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Indiana's Forests

1999-2003 Part A

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Indiana's Forests

1999-2003 Part A

USDA Forest Service
Forest Inventory and Analysis Program
North Central Research Station, St. Paul, MN

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Acknowledgments

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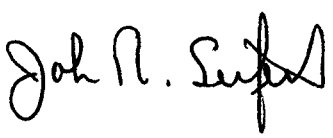
Note: A companion (Part B) of this document, available online, contains sample design and estimation procedures, quality of estimates analyses, and core tables of forest attributes.

Foreword

We welcome you to the latest results of our statewide forest inventory, *Indiana's Forests.* The inventory is conducted as a cooperative program between the Indiana Department of Natural Resources Division of Forestry and the Forest Inventory and Analysis program of the USDA Forest Service. Results of the inventory show that Indiana's forests are growing more wood than is being harvested providing Indiana's woodland owners and wood industry the economic engine to grow the State's economy. Our 4.5 million acres of forests supports $9 billion of economic activity each year. The Bio-Crossroads Report shows that hardwood timber and associated industries make up Indiana's largest agricultural sector. Every 1,000 acres of forest land directly supports 12 manufacturing jobs in the primary and secondary wood using industry. In addition, Indiana forests provide abundant wildlife habitat, recreation opportunities and watershed protection.

Indiana's forests are expanding and robust. But threats are on the horizon. Invasive species, parcelization, and conversion of forests to other land uses are all issues that will need attention in the future. Society expects a wide variety of goods and services from our forests. *Indiana's Forests 1999-2003* gives us a common set of statistically accurate numbers that we can use to make forest management decisions.

We invite you to read and interpret the results of *Indiana's Forests 1999-2003* and then participate in the discussions about the future of forests and forestry in Indiana.



John Siefert, State Forester

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Highlights

⊕ On the Plus Side

- Since 1950, Indiana's forest land has increased by nearly one-half million acres.
- Indiana's forests continue to support a great diversity of tree species.
- There are no major tree die-offs anywhere in the State; natural tree mortality appears evenly distributed across the State.
- The ratio of harvested tree volume to tree volume growth indicates sustainable management.
- Diverse and abundant forest habitat (coarse woody debris, snags, forest cover, and edges) supports healthy wildlife populations across the State.
- Due to the relatively low fuel accumulations, Indiana's forests pose low fire danger except in times of extreme drought.
- Indiana possesses a diversity of standing dead tree wildlife habitat with an abundance of recently recruited snags to replenish fully decayed snags as Indiana's forests mature.
- The growing-stock volumes of Indiana's economically important hardwoods have been increasing steadily over the past 50 years.
- Total sawtimber volumes on timberland are expected to reach nearly 30 billion board feet by 2008, roughly enough wood to cover all the floors of all homes in Indiana eight times.
- The volume of the highest grade sawtimber has steadily increased since 1986, both in terms of absolute volume and as a percentage of all graded sawtimber.
- The primary wood harvesting and processing industry in Indiana directly employs almost 9,000 people, with a payroll of $220 million (not including the 1,000's employed by secondary industries).
- Total live tree biomass for the forests of Indiana totals more than 228 million dry tons, roughly equivalent in weight to all the houses in Indiana.

Problem Areas

- Indiana's oak species continue to grow more slowly than numerous other hardwood species.
- The average private forest landholding dropped in size from 22 acres in 1993 to 16 acres in 2003, indicating continuing "parcelization" of forests.
- Forest insects, ranging from loopers to forest tent caterpillars, continue to defoliate forests, although natural controls are keeping these pests in-check.
- Introduced or invasive plant species inhabit a majority of inventory plots.
- The amount of forest edge doubled in southern Indiana between 1992 and 2001, indicating smaller forest parcels.
- The habitat provided by coarse woody debris is minimal in most areas of the State due to the lack of large pieces and the advanced stages of decay.
- Indiana's forests are exposed to ozone concentrations substantially above background levels, which could reduce growth and impair the health of Indiana's forests.
- Due to the natural factors and land use history, the forest soils of southern Indiana are generally below average in quality.
- Sawtimber volumes of white and red oak species have not increased significantly in the past 5 years.
- In the process of harvesting industrial roundwood from forest land, there were 21 million cubic feet of growing-stock material left on the ground as logging residue.

Issues to Watch

- Although Indiana's forest land area is still increasing, the rate has been diminishing over the past decade.
- Increases in total volumes of oak species are less than those for most other hardwood species.
- Indiana's forests continue to mature in terms of the number and size of trees within forest stands.
- The ratio of harvested sawtimber to total sawtimber has slightly increased since 1998.
- Tree-of-heaven, an invasive tree species, has established itself in forests along the Ohio River and could disperse farther into Indiana's forests.
- The advanced ages and inadequate regeneration of Indiana's oak forests may signal a successional shift from an oak/hickory-dominated landscape to one where other hardwood species, such as maples occupy more forested area.
- The emerald ash borer, an introduced insect, could have substantial ecological implications for the 1.75 million acres that support ash species in Indiana.
- Indiana's hardwood sawtimber resource continues to be at risk due to maturing of hardwood stands, loss of timberland to development, and new pests – gypsy moth, emerald ash borer, sudden oak death, beech bark disease, and more.
- Ownership of Indiana's forests has changed in the past decade, resulting in forest parcelization and fragmentation.

The Features, Health, and Products of Indiana's Forests

Forest Features

The Forest Land Base

Background:

Quantifying the amount of land occupied by forests is crucial to assessing the current status and trends in Indiana's forest ecosystems. Fluctuations in the forest land base may indicate changing land use trends and forest health conditions.

What We Found:

The area of forest land in Indiana is currently estimated to be more than 4.5 million acres. Forest land increased by nearly 52,500 acres between the last inventory (1998) and the current one (2003). Since 1950, forest land has increased by more than 450,000 acres (fig. 1.1). Despite this net gain in forest area, the amount of forest has fluctuated by county (fig. 1.2), with some counties in southern Indiana losing forest land (fig. 1.3).

What This Means:

While the area and extent of Indiana's forests have been increasing since the first forest inventory in 1950, the annual rate of increase has slowed since 1986 (0.15 percent between 1986 and 2003, 0.23 percent between 1950-1986). Additionally, rates of increase or decrease in forest area have been inconsistent across the State with some counties gaining forest area and others losing. Possible forest losses since 1986 in southern Indiana, in particular, should be noted within the context of sampling errors.

Chris Evans, The University of Georgia, www.forestryimages.org

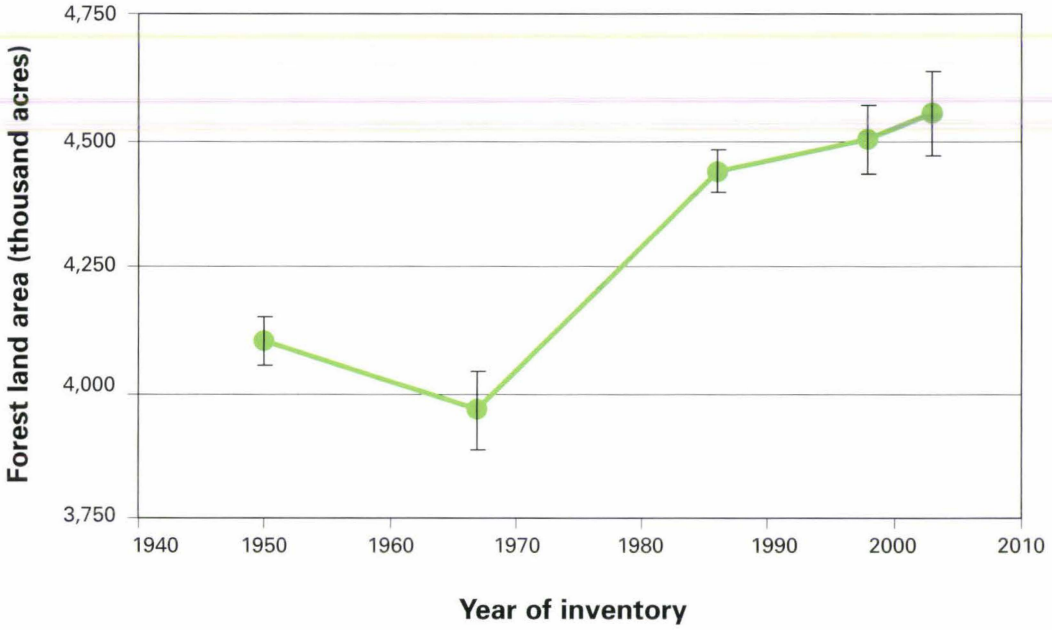


Figure 1.1. Area of total forest land area and associated standard error in Indiana by inventory year.

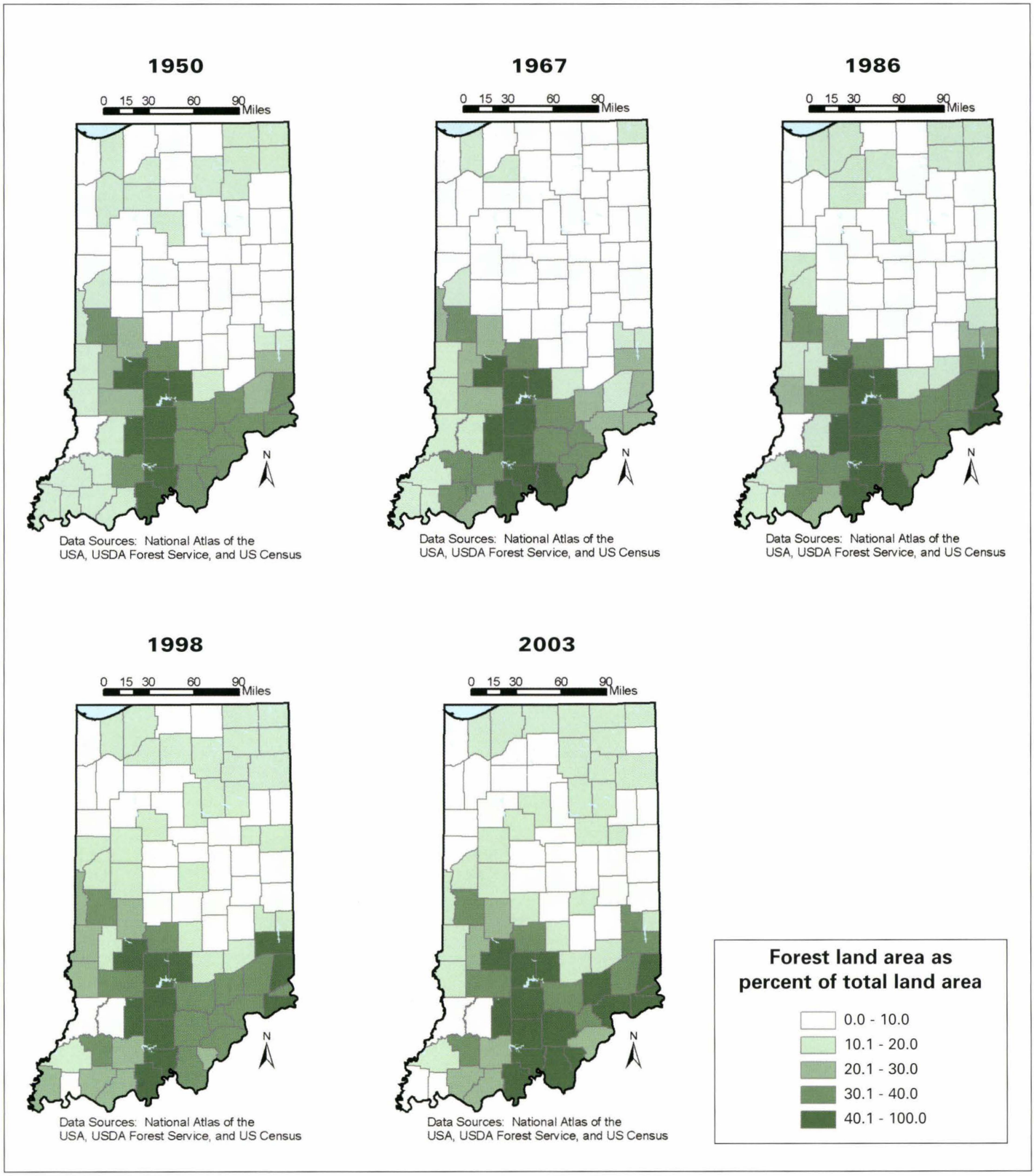

1950
0 15 30 60 90 Miles
N
Data Sources: National Atlas of the USA, USDA Forest Service, and US Census
1967
0 15 30 60 90 Miles
N
Data Sources: National Atlas of the USA, USDA Forest Service, and US Census
1986
0 15 30 60 90 Miles
N
Data Sources: National Atlas of the USA, USDA Forest Service, and US Census
1998
0 15 30 60 90 Miles
N
Data Sources: National Atlas of the USA, USDA Forest Service, and US Census
2003
0 15 30 60 90 Miles
N
Data Sources: National Atlas of the USA, USDA Forest Service, and US Census
Forest land area as percent of total land area
0.0 - 10.0
10.1 - 20.0
20.1 - 30.0
30.1 - 40.0
40.1 - 100.0

Figure 1.2. Distribution of forest land by county for five inventory years.

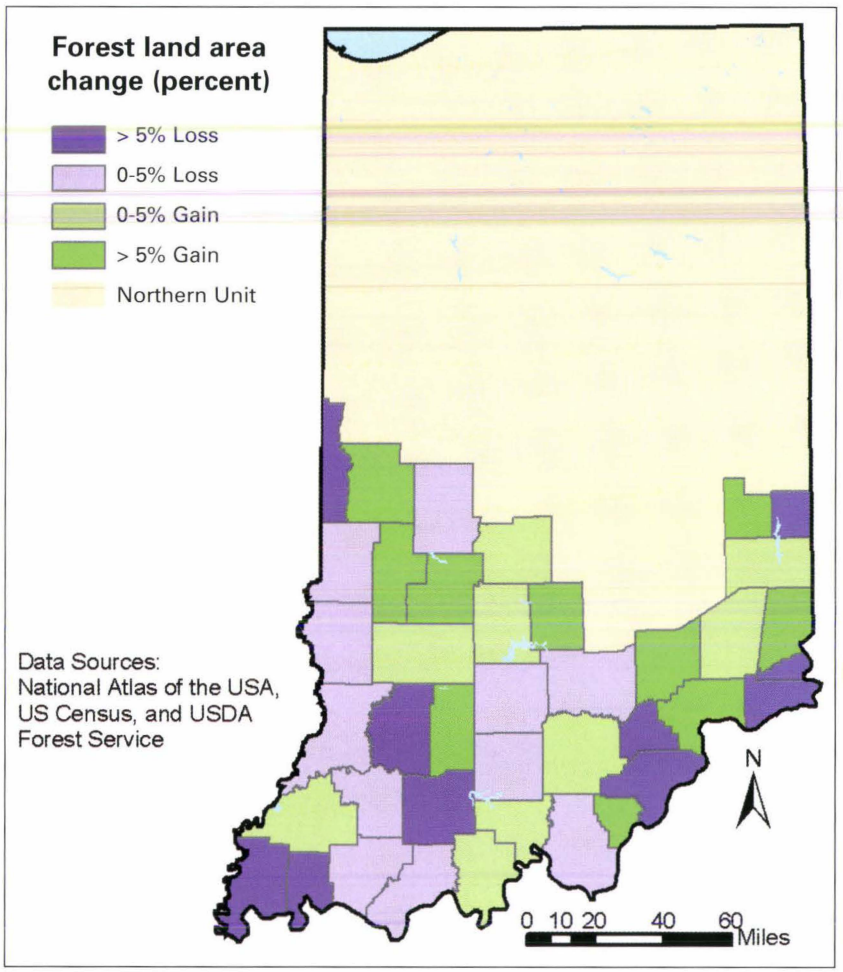


Figure 1.3. Change in forest land area as a percentage of total land area by county in southern Indiana between 1986 and 2003 (due to insufficient sample size, the northern survey unit was excluded from this analysis).

Biomass: A Weighty Issue

Background:

Together with measures of Indiana's forest acreage, estimates of total biomass and its allocation among stand components helps indicate forest health trends and sustainability of forest management activities.

What We Found:

The estimated total live tree biomass for the forests of Indiana exceeds 228 million dry tons. Live tree biomass (dry tons) is allocated among tree boles (70 percent), stumps/tops/limbs (24 percent), and small trees (6 percent) (fig. 1.4). Eighty-five percent of this material resides on private property (fig. 1.5). Non-growing-stock trees constitute an appreciable amount of forest biomass in Indiana (13 percent). As expected, the distribution of live tree biomass (dry tons) among Indiana counties is similar to the distribution of forest land (fig. 1.6). Counties in south-central Indiana, for example, have roughly five times as much living forest biomass as northern counties.

What This Means:

The maintenance of forest area for numerous decades across large portions of Indiana has allowed growth of a sizable amount of forest biomass. The largest amounts of forest biomass per acre are found in southern Indiana, where forests have existed for long periods of time. Because most forest biomass resides in the boles of growing-stock trees on private land, the management of these forests strongly affects the dynamics of Indiana's living carbon sinks. Other substantial pools of carbon are found in forest soils, standing dead trees, down dead trees, roots, and nontree vegetation (live and dead).

Bill Cook, Michigan State University, www.forestryimages.org

Figure 1.4. Distribution of live tree biomass (dry tons) among small trees (1-4.9 inches d.b.h.) and the boles, stumps, tops, and limbs of larger trees (>= 5 inches d.b.h.), Indiana, 1999-2003.

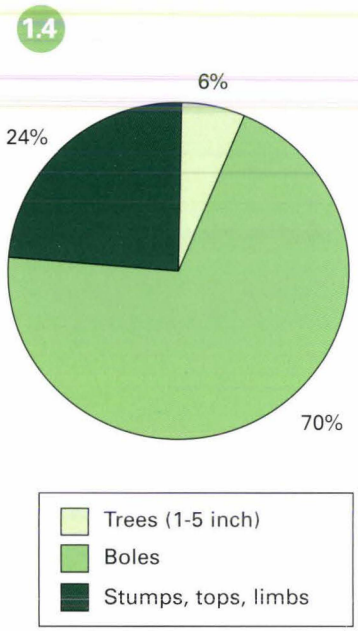


Figure 1.5. Ownership of forest biomass (dry tons) for growing-stock and non-growing-stock trees on timberland areas, Indiana, 1999-2003.

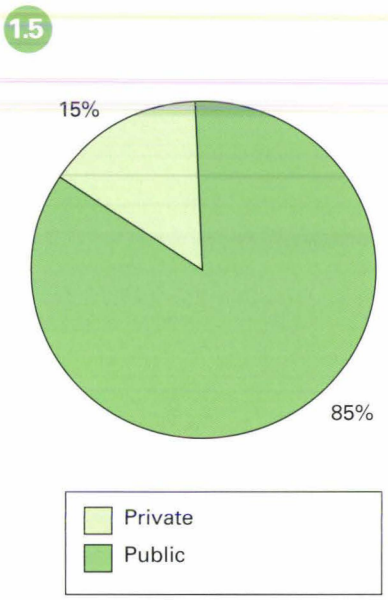
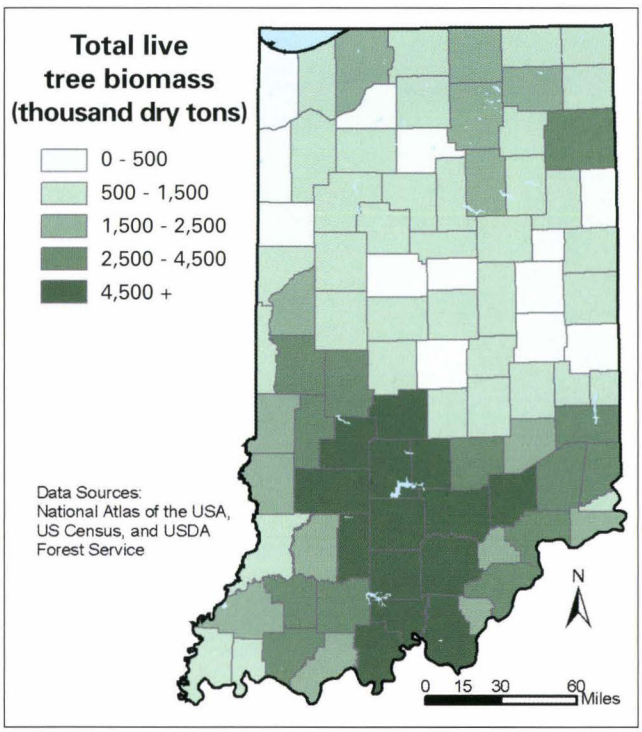


Figure 1.6. Total forest land tree biomass (dry tons) for Indiana counties, 1999-2003.



A Tapestry of Tree Species

Background:

The species composition of a forest stand drives the dynamics of its growth, development, and ecosystem function. The determination of current species compositions, along with trend analysis, allows quantification of current and potential forest ecosystem character.

What We Found:

Yellow-poplar is the most common species across Indiana today in terms of total live volume (fig. 1.7). Numerous other species, including ecologically and economically important hardwood species such as sugar maple, white oak, black oak, white ash, and northern red oak, contribute substantially to Indiana's forest volume. In terms of total number of trees, sugar maple dominates, with more than twice as many trees as the next most abundant species (American elm) (fig. 1.8). Other common species include sassafras, flowering dogwood, red maple, and black cherry. Overall, 80 individual tree species were recorded during the forest inventory. Although yellow-poplar and white oak are number one and three, respectively, in terms of total live volume across Indiana, they rank far lower in number of trees, indicating their large individual tree size compared with other species. The growing-stock volume of selected species has increased substantially since 1986, more than 100 percent in the case of yellow-poplar (fig. 1.9). However, black and white oak had volume increases of less than 20 percent during that period.

What This Means:

No single species dominates Indiana's forests in terms of both tree numbers and volume. Hardwood species such as oaks, hickories, yellow-poplar, and maples lead the way in total tree volume, while sugar maple, elm, sassafras, and dogwood contribute the greatest numbers of trees. These statistics reflect the ecological niches of individual species where certain species populate forest understories in large numbers (e.g., dogwood), while others dominate overstories with large trees in small numbers (e.g., white oak). However, there does appear to be evidence of a species composition shift in total volume since 1950. Some species that were minor stand components in 1950 (e.g., hackberry and eastern redcedar) now inhabit Indiana's forests in large numbers and contribute substantially to net volume growth. An exception is American elm, which has increased by only 8 percent in total volume since 1950. Elm inhabits Indiana's forests predominantly as small understory trees due to the negative effects of Dutch elm disease on older elm trees. Overall, Indiana's diverse hardwood forests have increased in terms of number of trees and volume since 1950, mostly as a result of increasing forest land and maturing stands.

Wendy VanDyk Evans, www.forestryimages.org

Figure 1.7. Top 12 tree species in terms of total volume of live trees (million cubic feet) occurring on Indiana's forest land, 1999- 2003.

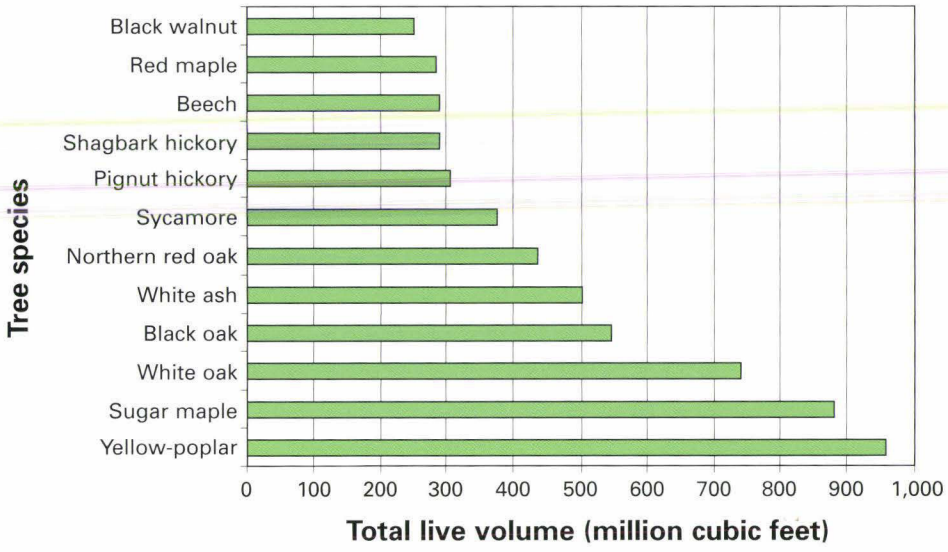


Figure 1.8. Top 12 species groups in terms of number of live trees (millions) occurring on Indiana's forest land, 1999-2003.

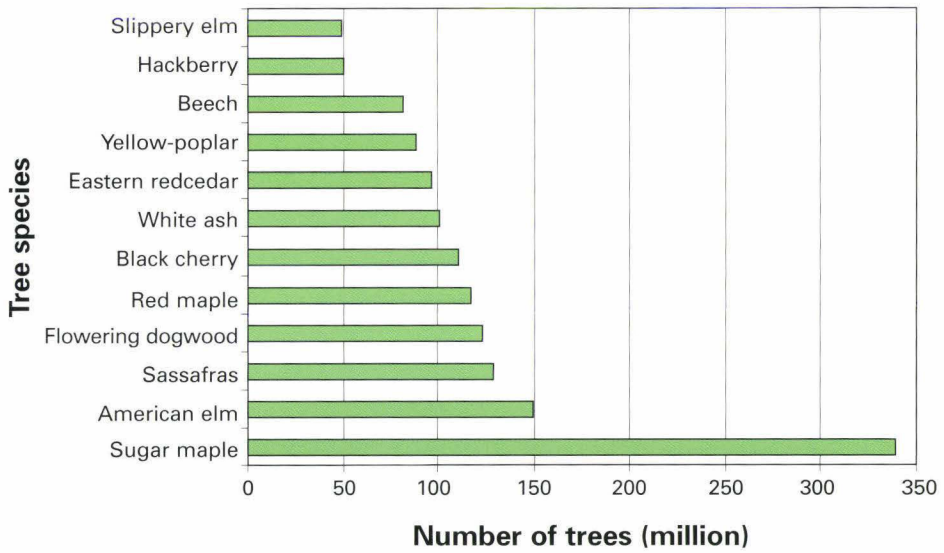
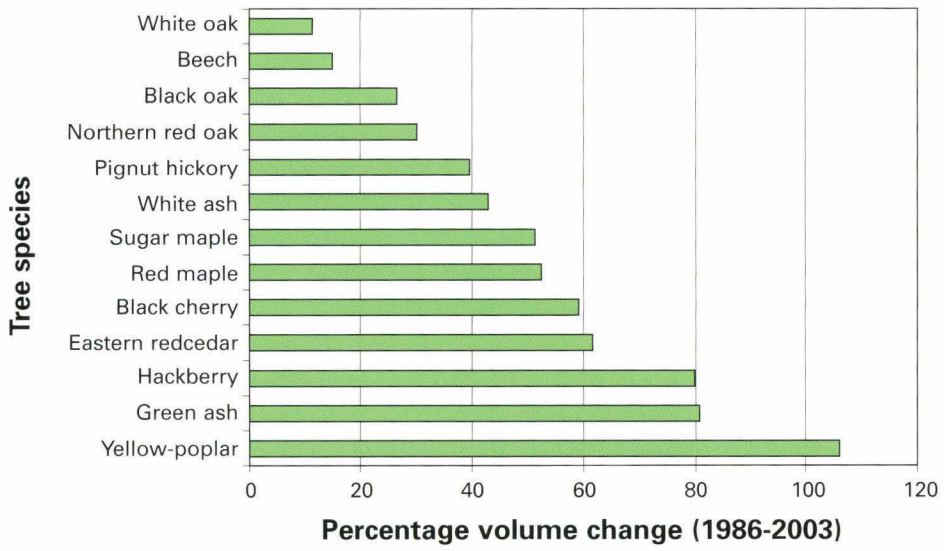


Figure 1.9. Percentage change in growing-stock volume for selected tree species on timber land between 1986 and 2003, Indiana.



How Thick Are The Woods?

Background:

The density of forest stands across Indiana may indicate the stages of stand development and the site occupancy of forests. Determining stages of stand development aids assessment of the future growth or mortality of forest resources.

What We Found:

Each acre of timberland in Indiana supports an average of 417 trees. This represents a decrease since 1998, reversing a trend of increasing numbers of trees since 1967 (fig. 1.10). Growing-stock volume, which has consistently increased on timberland since 1950 (fig. 1.11), is currently estimated at 1,704 cubic feet per acre. Basal area—the cross sectional area of trees measured 4.5 feet above the ground—serves as another measure of stand density. Basal area per acre varies widely across the state but is highest in southern Indiana where forests are concentrated (fig. 1.12). Basal area also varies considerably within areas of timberland.

What This Means:

A diversity of forest stand densities exists across Indiana, indicating varying stages of stand development and a range of ecological niches and processes. The number of trees per acre has fluctuated since 1950, at first decreasing, then increasing, and more recently decreasing again. As Indiana's forests continue to mature, the number of trees per acre should decrease while average volume and basal area should increase.

Figure 1.10. Average number of growing-stock trees per acre on timberland in Indiana, 1950-2003.

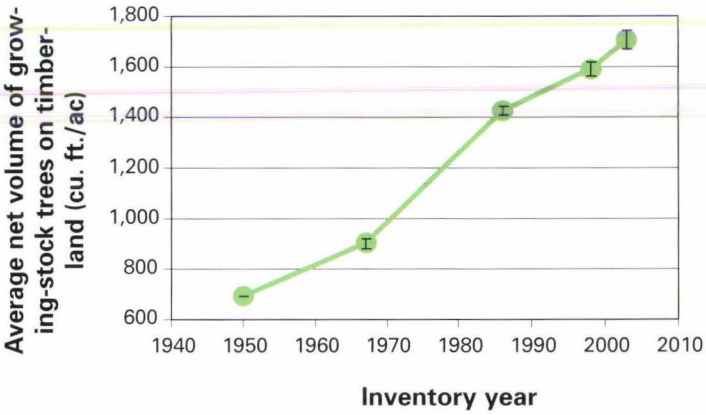
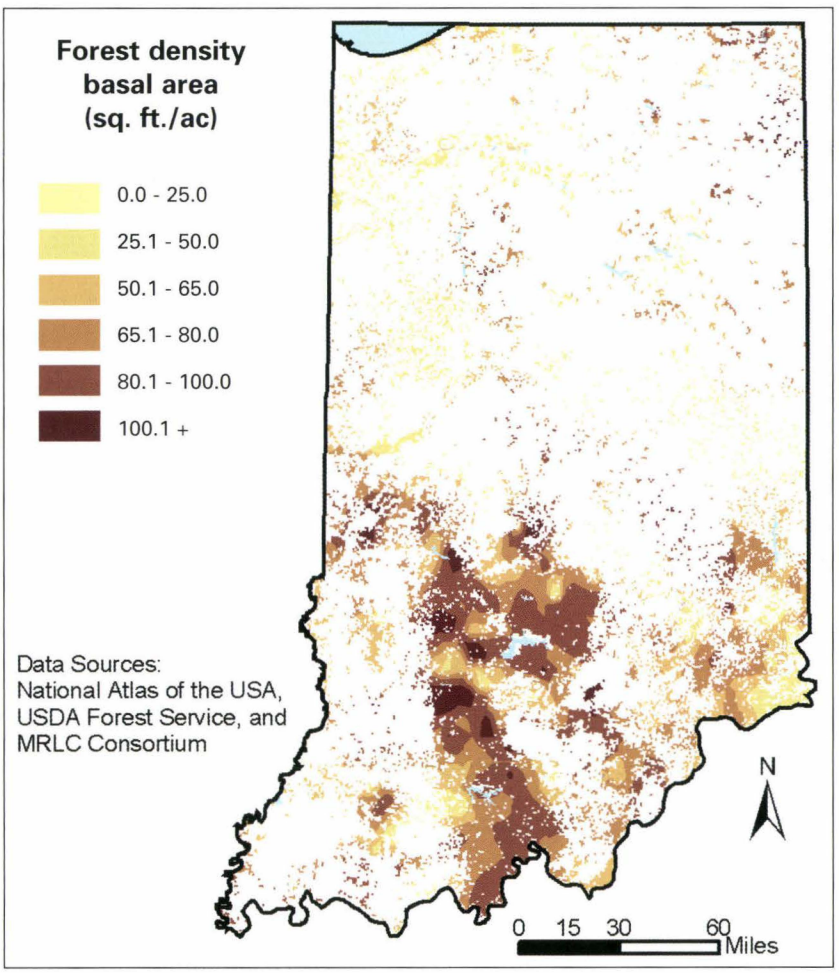


Figure 1.11. Average net growing-stock volume on timberland in Indiana, 1950-2003.

Figure 1.12. Distribution of tree basal area (inverse distance weighting interpolation) across Indiana's timberland,1999-2003.



Forest Growth: Upward and Onward

Background:

Examining the net growth of forest ecosystem components sheds light on the direction of forest succession and disturbance trends, accretion of forest resources, and vitality of various tree species groups.

What We Found:

Average annual net volume growth of Indiana's forests (growing-stock growth minus growing-stock mortality on timberland) has increased substantially since 1967 and is now estimated at 268.1 million cubic feet per year (fig. 1.13). The steepest increase in average annual net volume growth occurred since the last inventory in 1998. Yellow-poplar and "other eastern soft hardwoods" (e.g., Sassafras and American elm) had the largest average annual net growth between 1998 and 2003 (fig. 1.14). Other notable species groups experiencing high levels of average annual net growth were hard maple, ash, beech, and hickory. When comparing annual growing-stock net volume growth to the total amount of growing-stock volume among species, beech and yellow-poplar had the highest rates (fig. 1.15). Some species (e.g., hard maple) that had considerable total net volume growth had less growth per unit total volume when compared to their total amount of volume in Indiana. The average annual net increase in growing-stock volume for all species in Indiana is currently a little over 3 percent per year.

What This Means:

Indiana's forests are currently growing at their fastest rate in the past six decades. The almost exponential annual net growth rate since 1967 can most likely be attributed to increasing forest area filling with increasing numbers of trees that are growing larger each year. Net volume growth is not uniformly distributed among all species groups; certain hardwoods (e.g., yellow-poplar) appear to be dominating. While hardwoods in general are showing net volume growth, all oak species appear to be growing more slowly than other hardwood species. For example, the accretion rate for "other red oaks" and "select white oaks" is less than 2 percent per year, while beech and yellow-poplar have growth rates exceeding 12 percent and 5 percent a year, respectively. Although oak species may be economically desirable, the faster growth of numerous other species suggests that oak forests may play less of a role in the future growth of Indiana's forests. Given these disparate rates of volume growth, the future species composition of Indiana's forests will certainly be different from that of today.

Paul Bolstad, University of Minnesota, www.forestryimages.org

Figure 1.13. Average annual net growth of growing-stock per unit of timberland acreage in Indiana, 1950-2003.

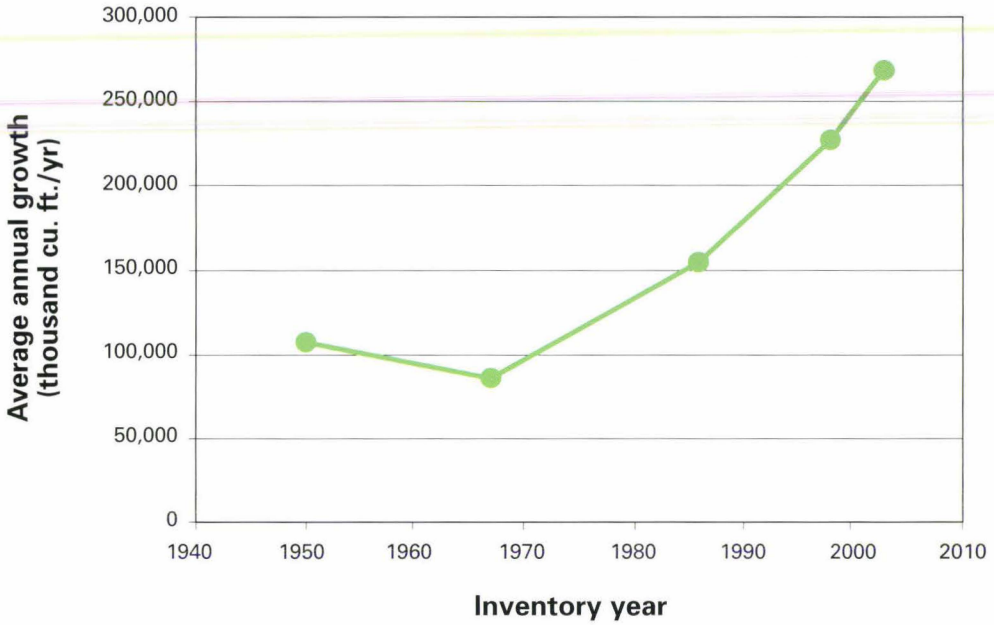


Figure 1.14. Average annual net growing-stock volume growth on timberland for selected species groups in Indiana, 1999-2003.

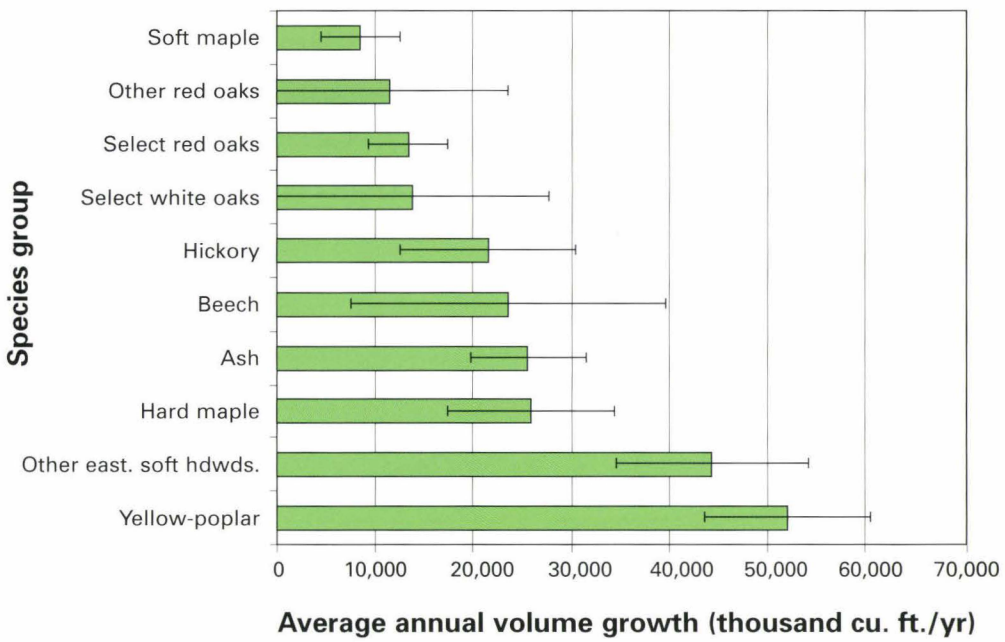
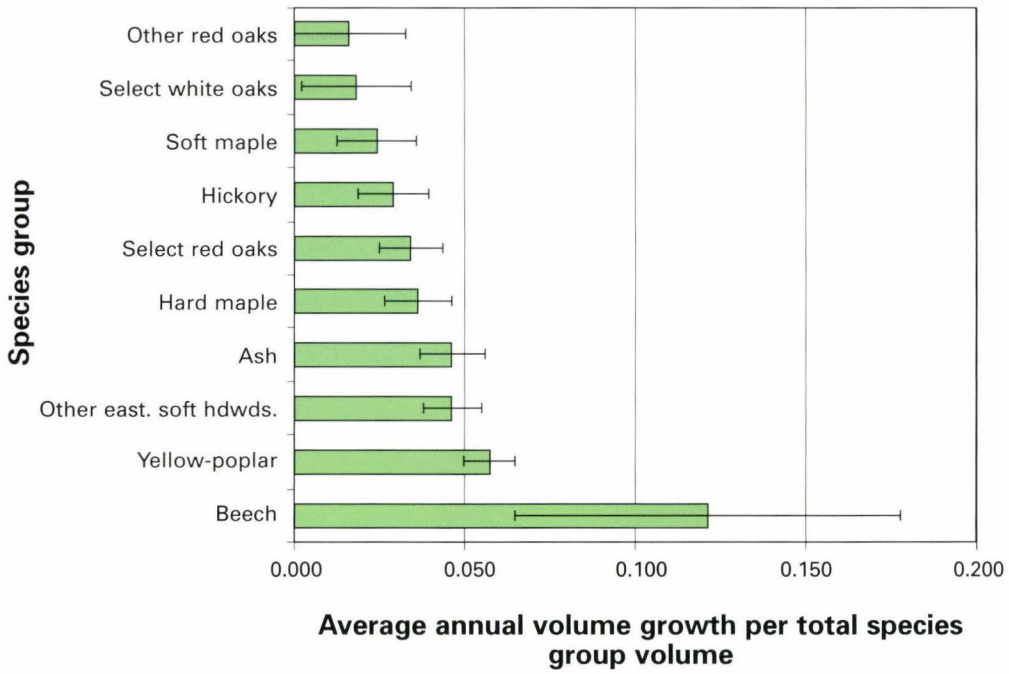


Figure 1.15. Ratio of the average annual net volume growth by total growing-stock volume on timberland for selected species in Indiana, 1999-2003.



Are Oaks Diminishing?

Background:

Oak forest types dominate the Indiana landscape. Not only are oak trees a vital component of Indiana's hardwood industry, they also provide food and habitat for numerous wildlife species. Successful regeneration and development of oak seedlings and saplings is critical to the future of the State's oak resource.

Paul Wray, Iowa State University, www.forestryimages.org

What We Found:

Seedlings are defined as trees with a diameter at breast height of less than 1 inch, while saplings are defined as trees having a diameter at breast height between 1 and 4.9 inches. On average, there are less than 100 oak seedlings per acre across all forest lands in Indiana (fig 1.16a). Species such as hard maple, ash, and hickory tend to have substantially more seedlings per acre than oaks. The pattern is similar for saplings, with oaks having substantially fewer saplings per acre on average than many other hardwoods (fig. 1.16b). Oak regeneration in oak forests is poor, with the ratio of oak seedlings/saplings to non-oak seedlings/saplings nearly 1 to 4 on average (fig. 1.17a-b). Site quality appears to have only a minimal effect on the regenerative ability of oak forests, with better sites showing only slightly more oak regeneration.

What This Means:

The future of Indiana's forests is sprouting today. Given the large seedling and sapling counts of non-oak species across the State's forests, Indiana's forests in the future may not be dominated by oaks to the degree they are today. Maples and beeches, which currently have relatively high seedling and sapling counts, are considered climax species across large areas of Indiana. This, in conjunction with the aging of Indiana's oak forests, may indicate a successional shift from an oak/hickory dominated-landscape to one where other hardwoods species occupy more forest land. Because oaks appear better able to regenerate successfully on the highest quality sites, these sites may maintain their current species composition farther into the future. However, it is clear that oak species will face increasing competition from other species as Indiana's forests continue to develop.

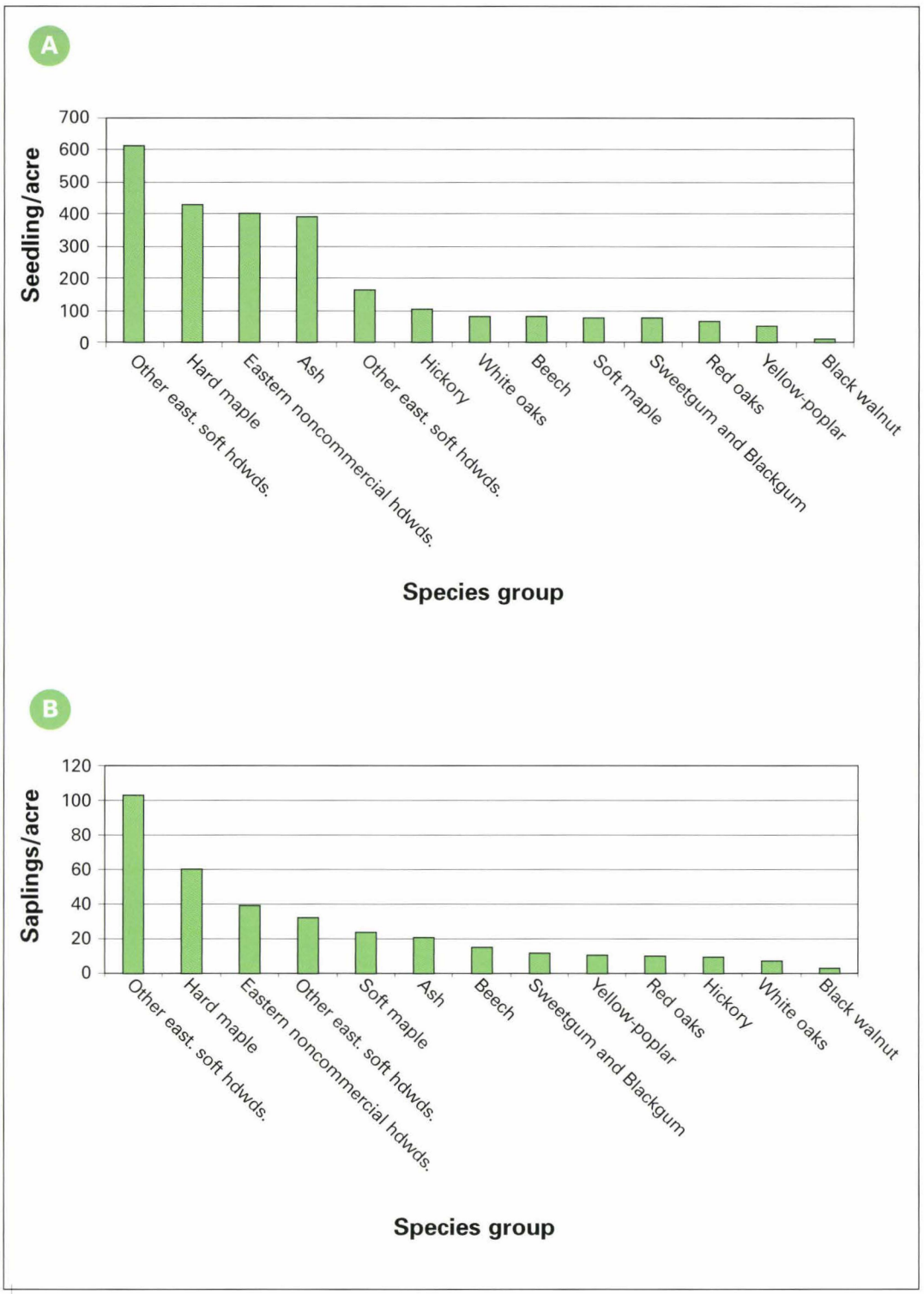


Figure 1.16. Mean number of seedlings (A) and saplings (B) per acre for major forest types in Indiana, 1999-2003.

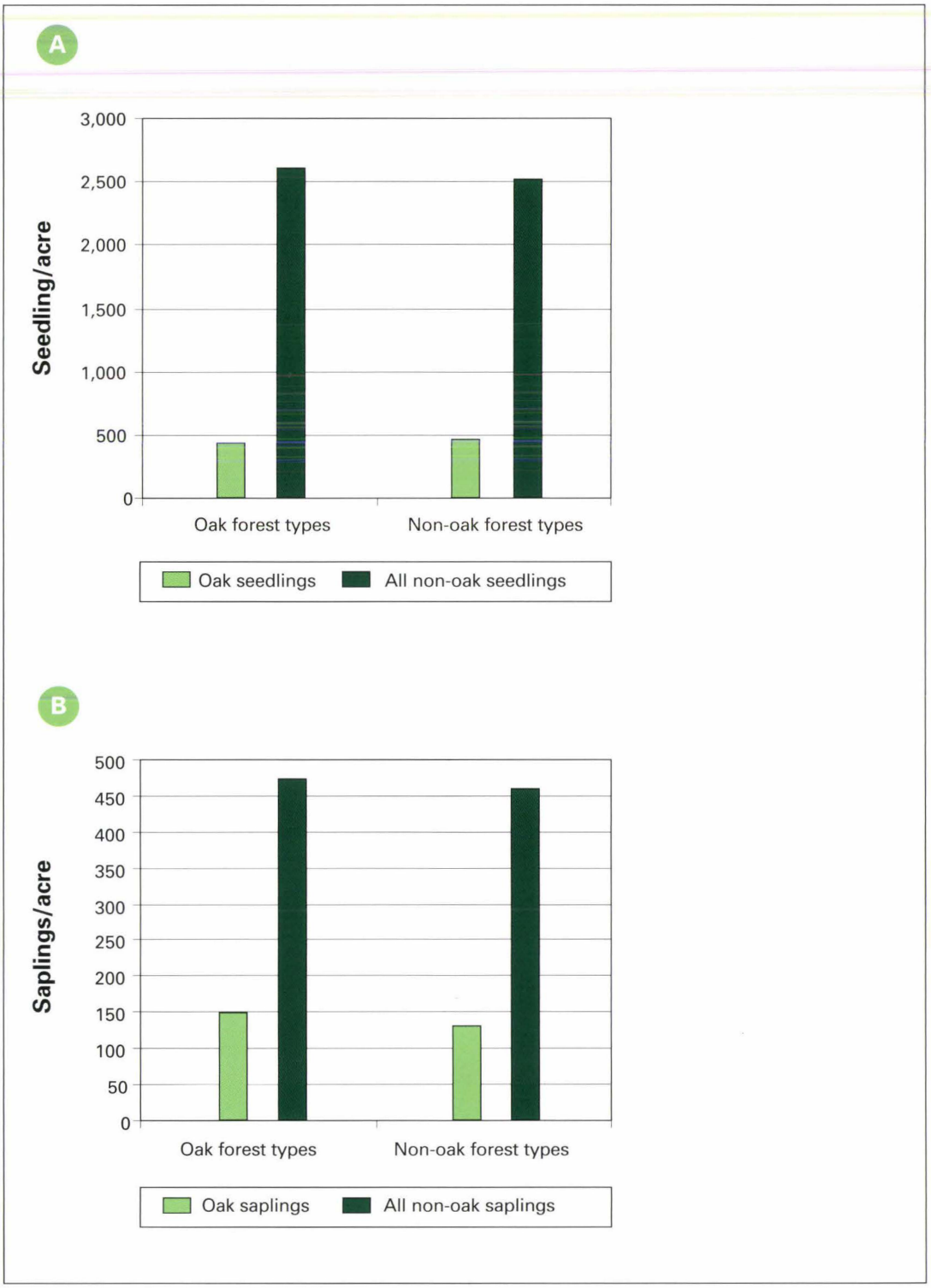


Figure 1.17. Mean number of seedlings (A) and saplings (B) per acre for oak and non-oak species on oak and non-oak forest types in Indiana, 1999-2003.

Tree Mortality: What Grows Up, Eventually Comes Down

Background:

Mortality has a strong influence on rates of forest resource accretion or depletion. Some mortality is a natural result of stand development, while some results from forest pests, and stress induced by a combination of biotic (insects, fungi, and plants) and abiotic agents (air pollution and drought). Although tree mortality is a natural process, a forest is defined as unhealthy when its mortality exceeds its capacity to respond (resiliency in terms of growth and regeneration).

What We Found:

The average annual growing-stock mortality rate for Indiana is currently estimated at 66.8 million cubic feet. Comparing current mortality rates with those in the past is difficult because sampling techniques used to assess mortality can't determine the exact time of death of any individual tree. However, average annual mortality per unit of timberland appeared to increase steadily between 1950 and 1996 (fig. 1.18). Between 1998 and 2003, there was no apparent change in mortality rates per unit of timberland. Total volume of mortality varied by species, with the "other eastern soft hardwoods" group showing the most mortality, followed by "other red oaks," "hickory," and "hard maple" (fig. 1.19). When species group total mortality volume is divided by the total volume of the species statewide in 2003, "white and red pines" have the highest mortality rate, followed by "jack pine," "other hard hardwoods," and "other yellow pines" (fig. 1.20). Statewide, the average annual mortality rate is approximately 0.9 percent. On a county-by-county basis in southern Indiana, there is no pattern of widespread tree mortality that would indicate insect or disease epidemics (fig. 1.21).

What This Means:

Overall, tree mortality in Indiana's forests appears to lie within the normal range. Although average annual mortality has increased since 1950, Indiana's forests have matured during this period, making them more susceptible to natural mortality. The rate of volume mortality for the state is very low—below 1 percent per year. Although hardwood species account for most of the total volume of mortality, pines have the highest mortality rates (about 3 percent). This could indicate a transition from early-successional species to those typical of later stages of stand succession. Although a few counties show slightly higher mortality rates, there are no "hotspots" that would indicate a serious threat. Mortality trends appear reasonable for Indiana; however, the advanced ages and stages of stand development prevalent across Indiana should be monitored as an indicator of future tree mortality.

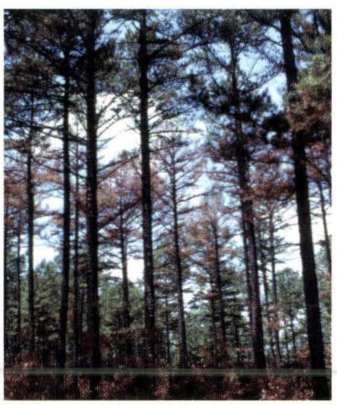


Figure 1.18. Average annual mortality of growing-stock per unit of timberland acreage in Indiana, 1950-2003.

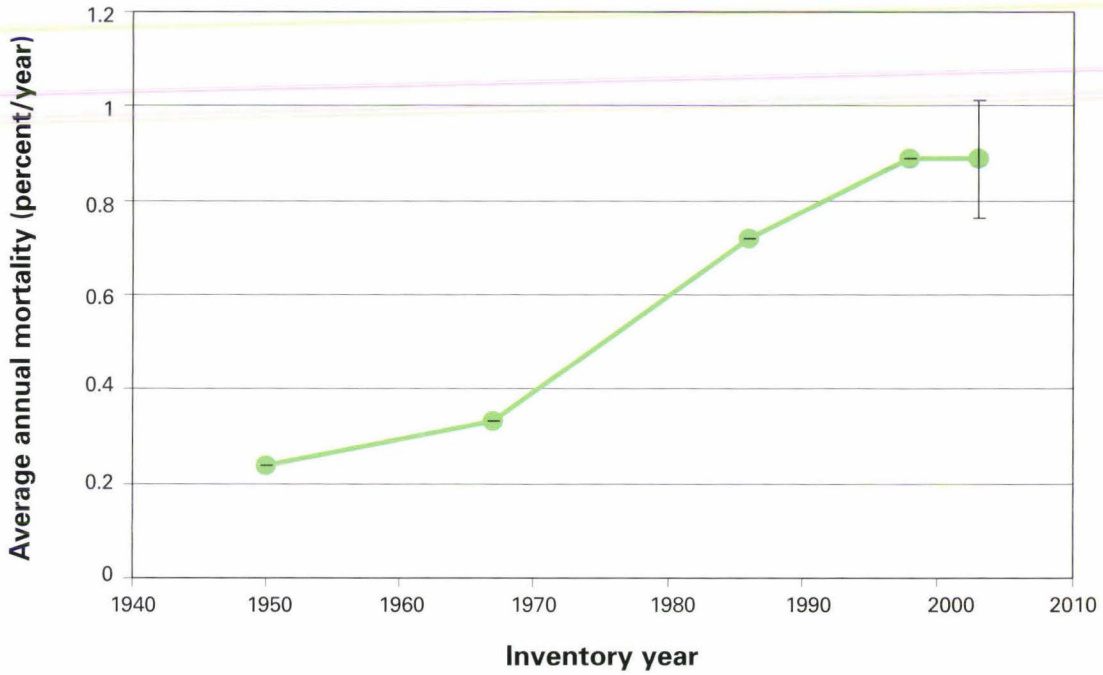


Figure 1.19. Average annual mortality of growing-stock on Indiana's timberland by selected species groups,1999-2003.

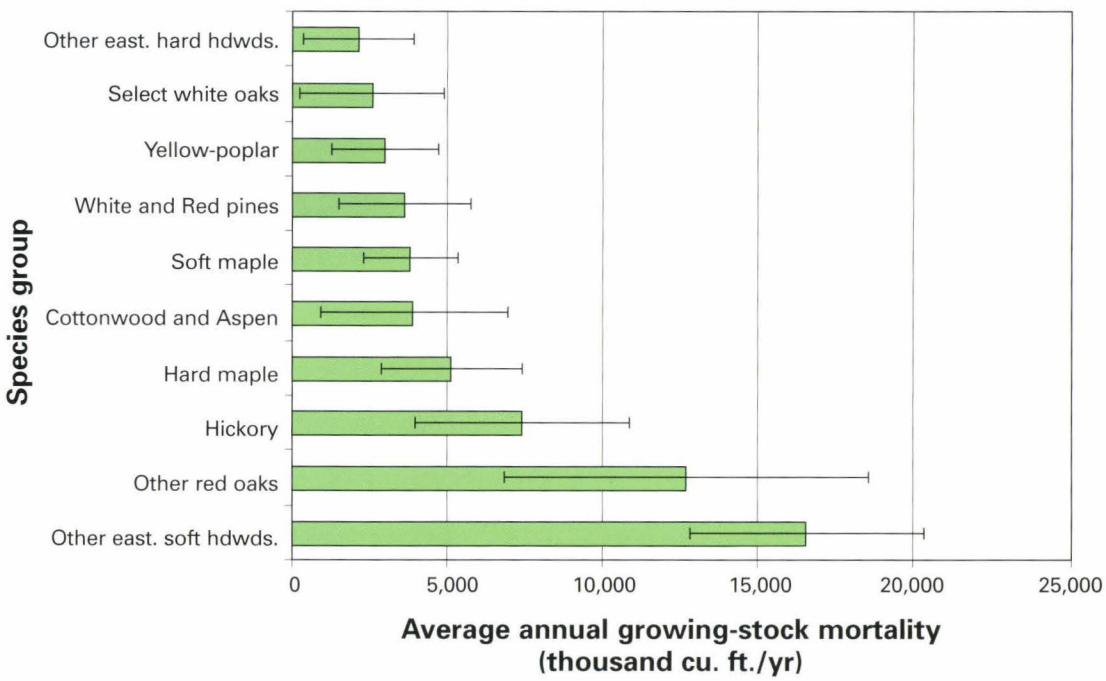


Figure 1.20. Average annual mortality of growing-stock per unit volume of growing-stock on timberland by selected species groups in Indiana, 1999-2003 (note: standard error missing for Jack pine due to insufficient sample size – it can be assumed to be relatively large).

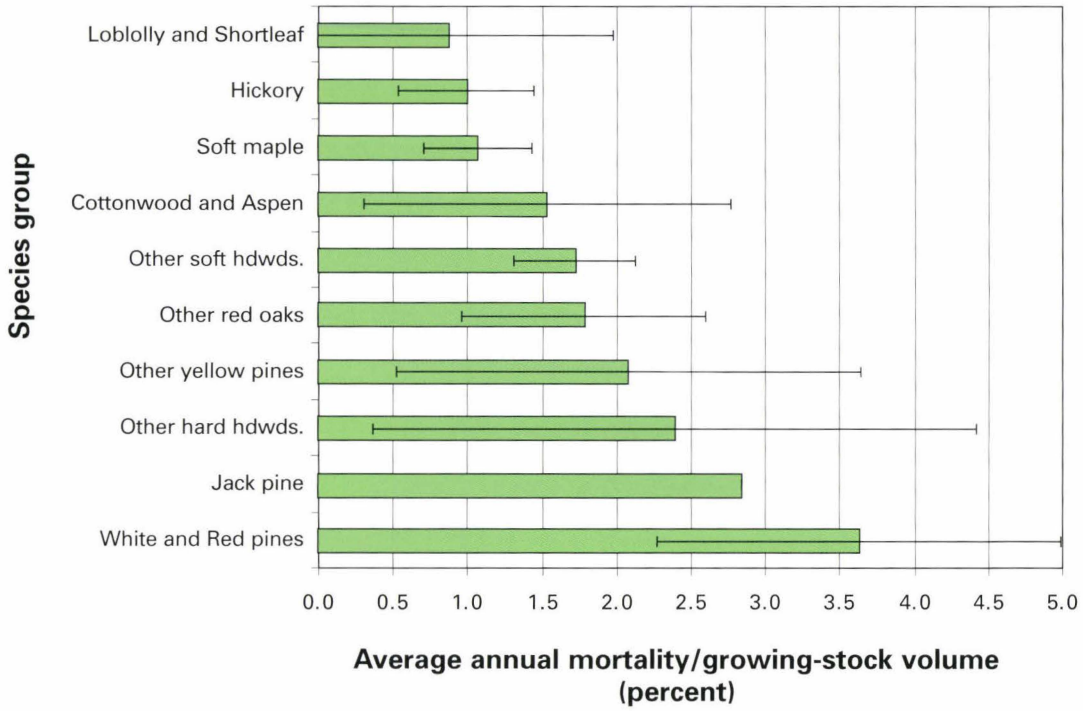
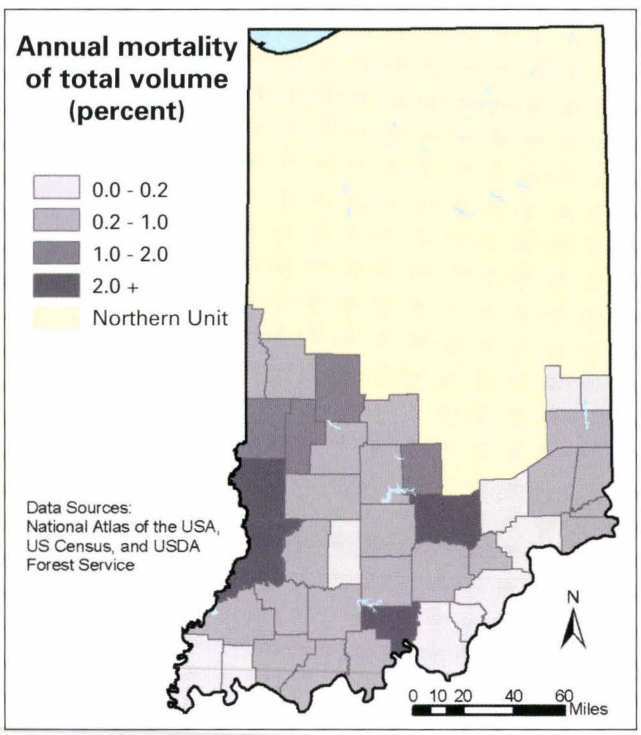


Figure 1.21. Average annual mortality of total growing-stock volume on timberland by county in Indiana (counties in northern survey unit excluded due to insufficient sample size), 1999-2003.



Tree Removals

Background:

The quantity of growing-stock removed from timberland by human means (i.e., land clearing and management activities) may indicate trends in forest management or land conversion in Indiana's forests. Because removals are observed on only a limited number of inventory plots, estimates show greater variances than those for mortality or timberland area.

What We Found:

The current average annual volume of growing-stock removal is estimated at 129.9 million cubic feet. Although the ratio of average annual removals to total growing-stock on Indiana's timberland has increased slightly since 1998 (fig. 1.22), the highest rates of extraction occurred in the 1950s and 1960s. The current rate of extraction is almost twice the rate of natural mortality (figs. 1.18 and 1.22). Yellow-poplar had the greatest volume of removals, almost twice that of select white oaks (fig. 1.23). Next came hickory, other red oaks, and other eastern soft hardwoods. White and red pines, followed by soft maple, other white oaks, and yellow-poplar had the highest ratios of average annual removals to total growing-stock volume (fig. 1.24). Although ratios of annual removals to total volume vary widely when mapped by county, ratios appear higher in the southwestern corner of the State (fig. 1.25).

What This Means:

Although the ratio of harvest to total growing-stock has increased steadily since 1986, removals appear to be consistent and sustainable. Even species with the highest average annual removals (yellow-poplar, select white oak, hickory, and other red oak) have removal rates of less than 3 percent. For most species, especially yellow-poplar, the rate of extraction is less than the rate of annual net growth, resulting in a net annual accretion of volume across Indiana. For some species, other red oaks in particular, removals nearly equal net growth. Because removal activity appears unequally distributed across Indiana's forested regions, attention should be paid to balancing removal amounts with growth and mortality to sustain resource levels at local scales.

Figure 1.22. Average annual removals of growing-stock on timberland in Indiana, 1950-2003.

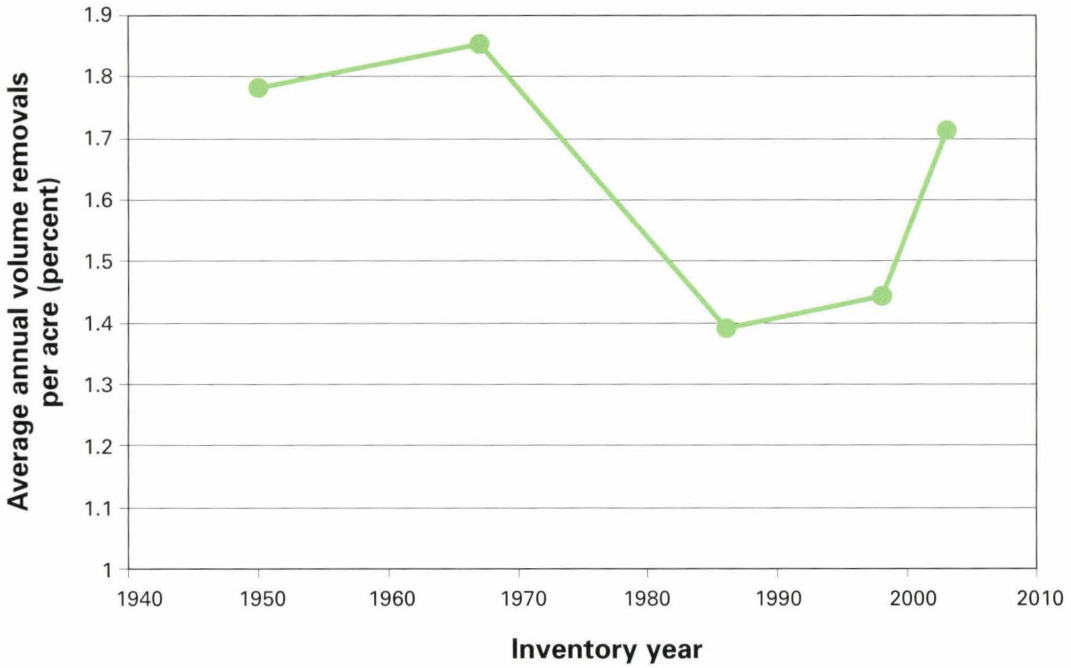


Figure 1.23. Average annual removals of growing-stock on Indiana's timberland by selected species groups,1999-2003.

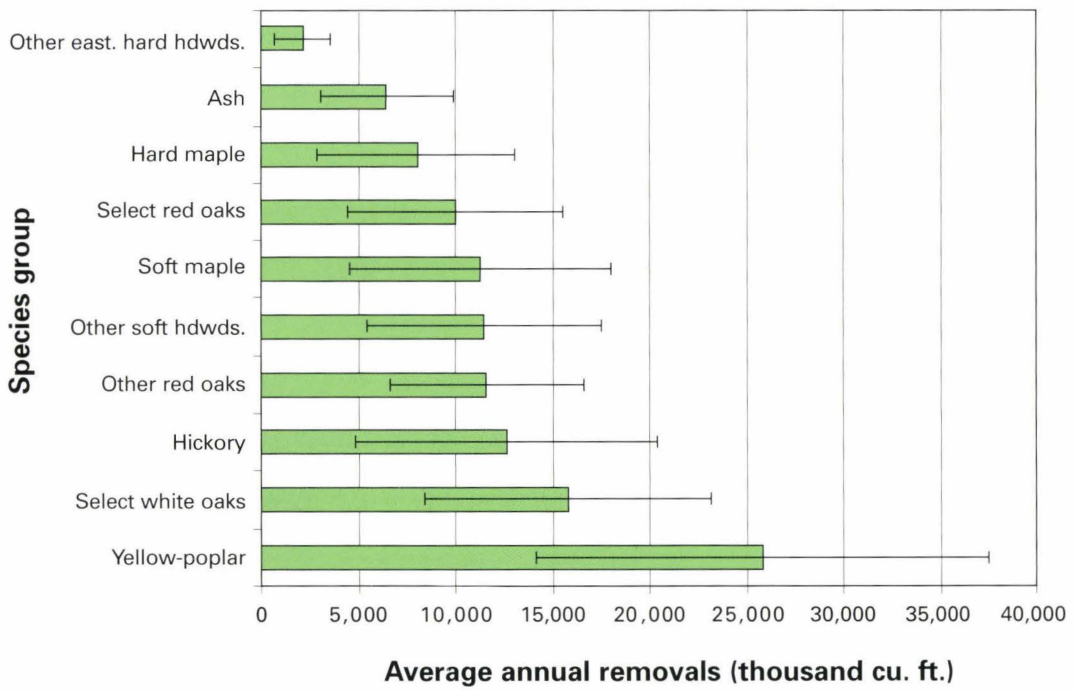


Figure 1.24. Average annual removals of growing-stock per unit volume of growing-stock on timberland by selected species groups, 2003.

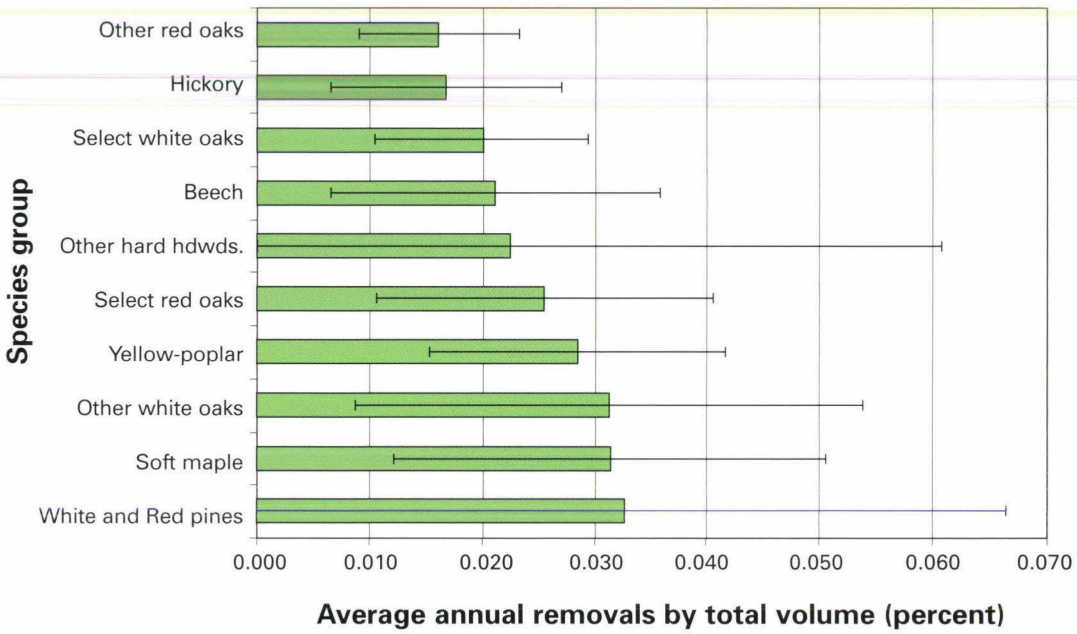
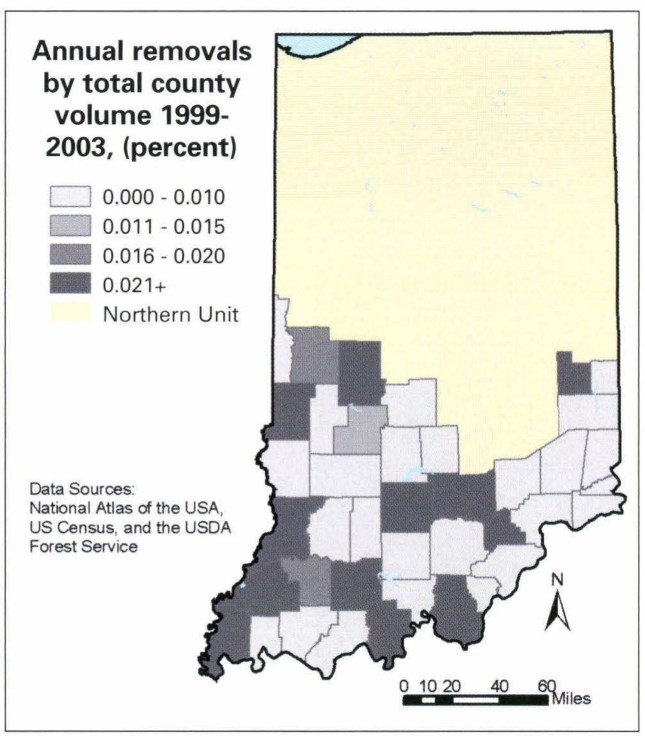


Figure 1.25. Average annual removals of growing-stock divided by total timberland area by county in Indiana (excluding counties in the northern survey unit), 2003.



Tree Growth: Fast or Slow?

Background:

The relationship between tree diameter and age is critical in assessing growth rates and stages of stand development across forest conditions. Greater ratios of diameter to age indicate faster growing trees, while widespread declines in diameter/age relationships may indicate maturing forest stands or those succumbing to insects or diseases.

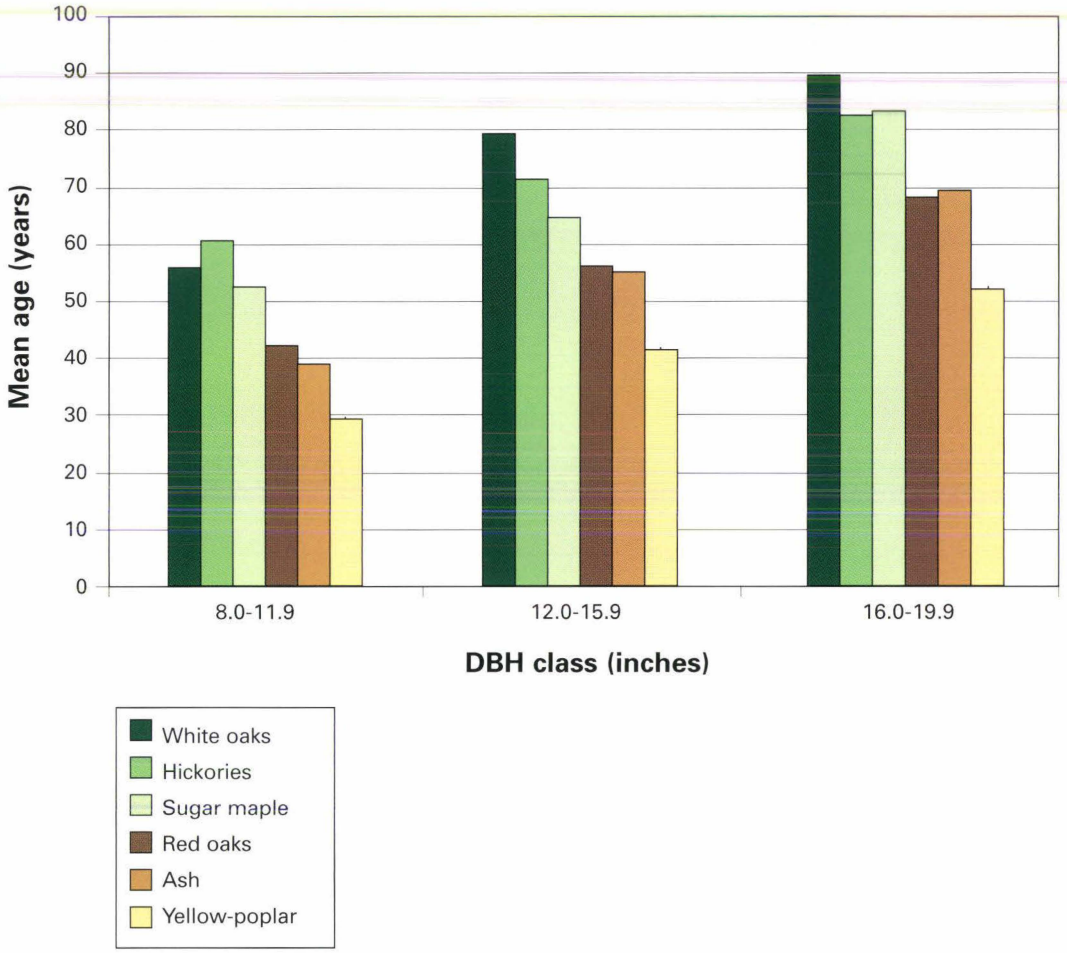
What We Found:

During the inventory we determined the ages of more than 1,500 trees by coring, allowing us to analyze diameter/age relationships for many of Indiana's common tree species. Differences among species were pronounced, with white oaks showing relatively slow growth compared with faster growing species like yellow-poplar (fig. 1.26). A 10-inch (d.b.h.) white oak in Indiana on average may exceed 50 years in age, while an 18-inch (d.b.h.) yellow-poplar may also average 50 years in age. Because site is often an important predictor of growth, we examined the relationship between tree diameter and age across a range of sites (fig. 1.27a-b). When evaluating diameter/age relationships by broad physiographic site classes, it is obvious that moist sites sustain more rapid tree growth than dry (xeric) sites (fig. 1.27a). Within mesic sites, flatwoods and broad floodplains have the fastest growth rates (fig. 1.27b).

What This Means:

Examining tree age/diameter relationships can provide insights into stand development patterns across Indiana. Age analyses showed yellow-poplar growth rates nearly twice those of other common tree species (e.g., white oak). Yellow-poplar is known for prolific growth rates when it occurs on mesic sites, whereas oak species often grow more slowly or are outcompeted on these sites. Other trees of economic interest, such as red oaks and ashes, also grew more rapidly than white oaks. Red oaks and ashes averaged 20 years younger than white oaks when considering large trees (d.b.h. greater than 16 inches). Within mesic sites, flatwood and broad floodplains had the fastest tree growth, indicating that slight variations in moisture can affect tree growth and competition across Indiana's productive forest lands.

Figure 1.26. Mean age versus diameter class for six common Indiana tree species groups, 1999-2003.



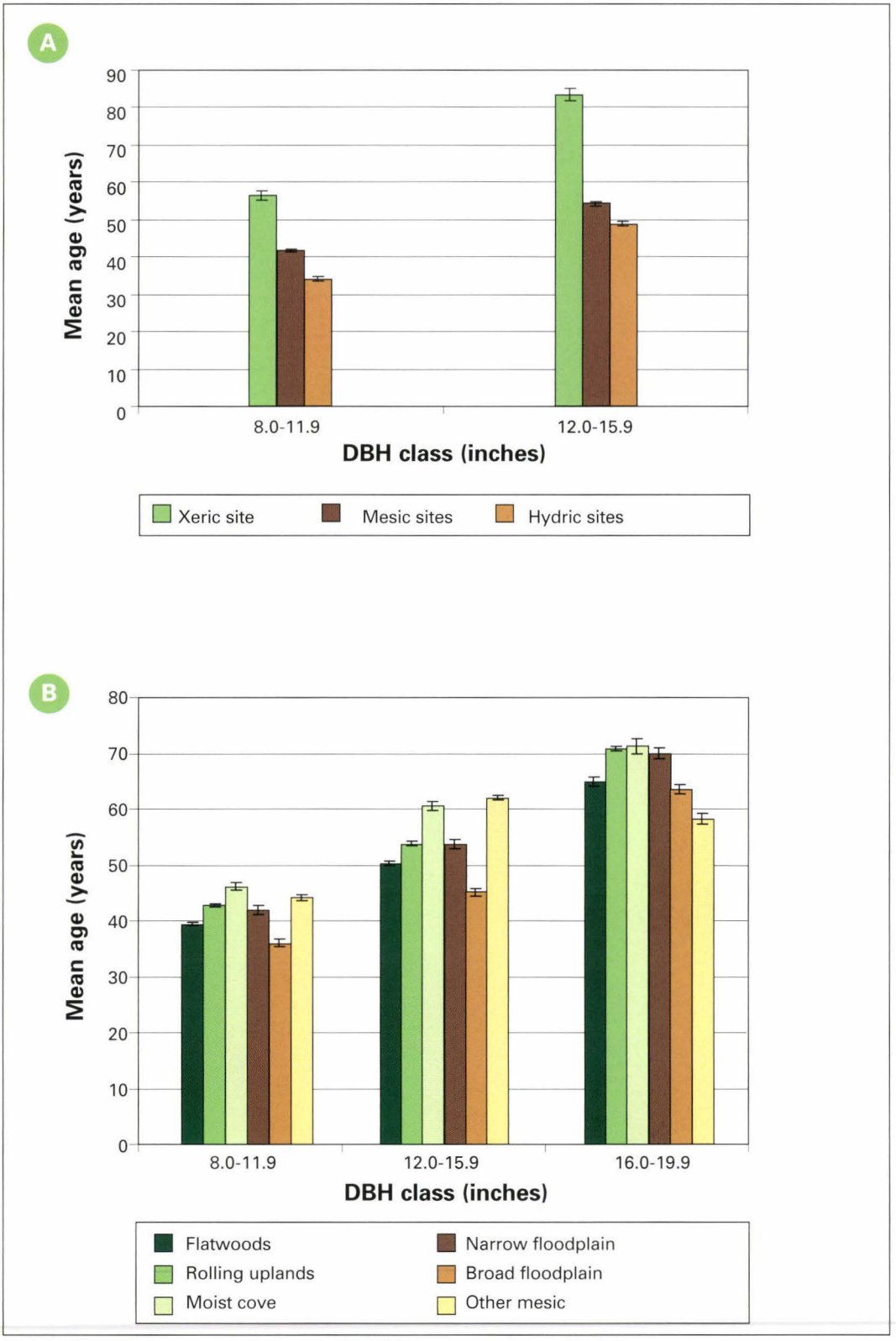


Figure 1.27. Mean age and associated standard errors by diameter class for the (A) three major physiographic classes and (B) divisions of the mesic physiographic class in Indiana, 1999-2003.

Whose Woods Are These?

Background:

The fate of Indiana's forests lies in the hands of the people and organizations who own them. The goods and services produced and provided by forests are a function of the forest land owners' objectives, opportunities, and constraints. Continued pressures from a changing society are altering what landowners can and will provide.

What We Found:

We used data from the National Woodland Landowner Survey to assess the attributes of Indiana's woodland owners (see Butler and Leatherberry 2005). Indiana's forests are predominantly privately owned (fig. 1.28a-b), with an estimated 205,000 families and individuals owning 3.3 million acres, or 74 percent, of the State's forest land. The other 26 percent is owned by private businesses, organizations (included incorporated farms), and public agencies. The number of family forest owners in Indiana increased dramatically over the last decade, while the average landholding size dropped from 22 acres in 1993 (Birch 1996) to 16 acres in 2003. Fifty-six percent of family forest land is now in parcel sizes of less than 50 acres (fig 1.29). Reasons commonly cited for owning forest land in Indiana include scenic beauty, protection of nature, privacy, and an asset to pass on to future generations. Seventy-six percent of forest land owners have their primary residence on or near (within 1 mile) their land. Nearly 60 percent of family forest land owners harvest trees for sawtimber and firewood; half of these owners have harvested trees within the past 5 years (fig. 1.30). While 26 percent of forest land owners have sought forest management advice, only 7 percent have written management plans. Even though insects and diseases are a common concern of many forest land owners, the most pressing concerns are social in nature—trespassing, illegal dumping, property taxes, and ability to pass the land on to future generations. Family legacy rates high as a concern partly because 38 percent of the owners are 65 years or older and many plan to pass some or all of their forest land on to heirs in the near future.

What This Means:

The composition of Indiana's forest land owners has changed over the years and will continue to do so. The process of parcelization—the dividing up of forest landholdings into smaller parcels—is likely to continue as long as land development pressures persist and few incentives remain for maintaining working forest lands. The age profile of owners and their stated intentions indicate that a large amount of forest land will soon be transferred to new owners. This changing ownership will offer new opportunities and challenges for those interested in the future of Indiana's forest resources.

Figure 1.28a-b. Forest land area and associated standard errors by ownership type (private=a, public=b) for Indiana, 2003.

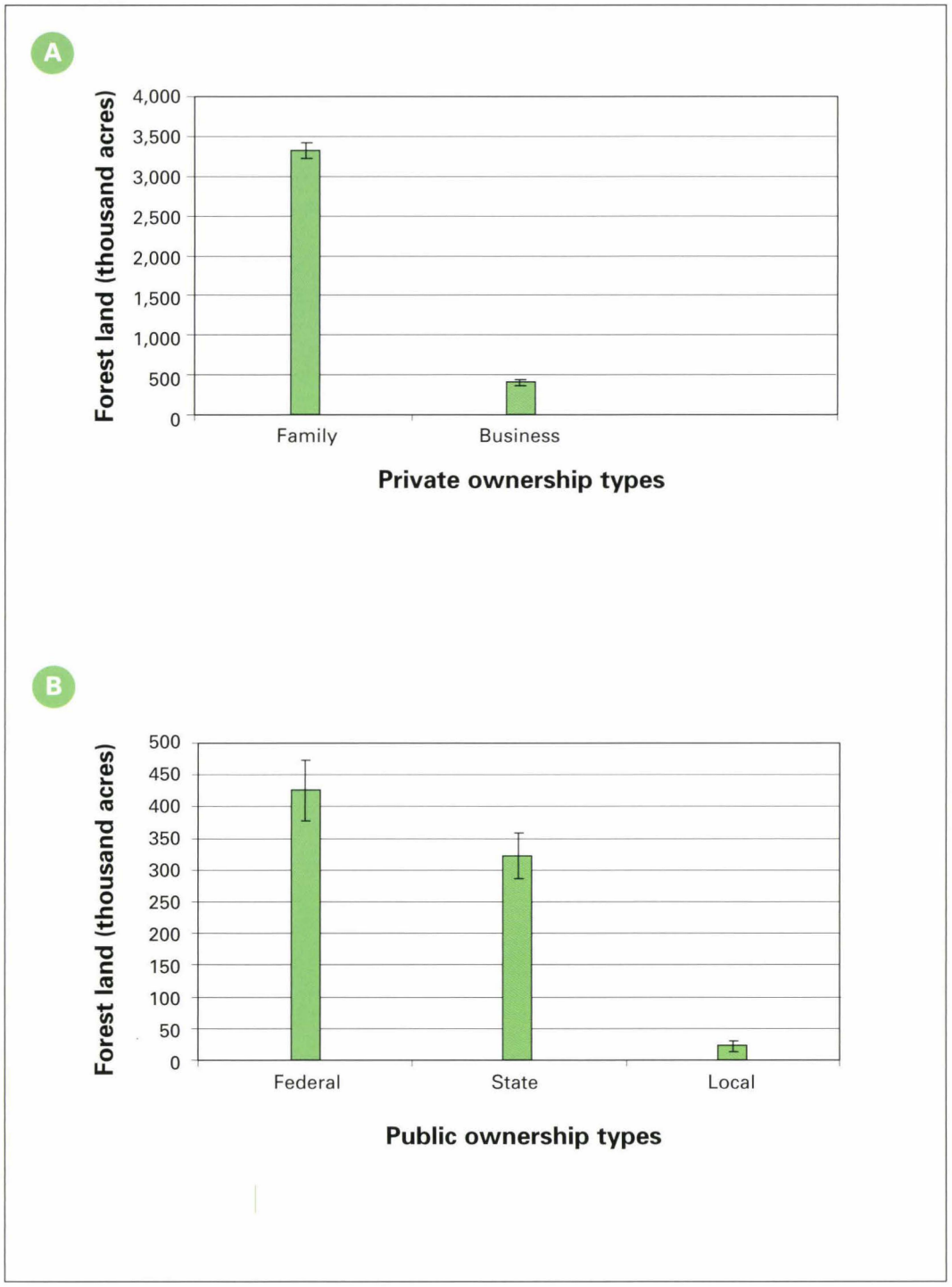


Figure 1.29. Area of family owned forests in Indiana by size of forest landholdings, 2003.

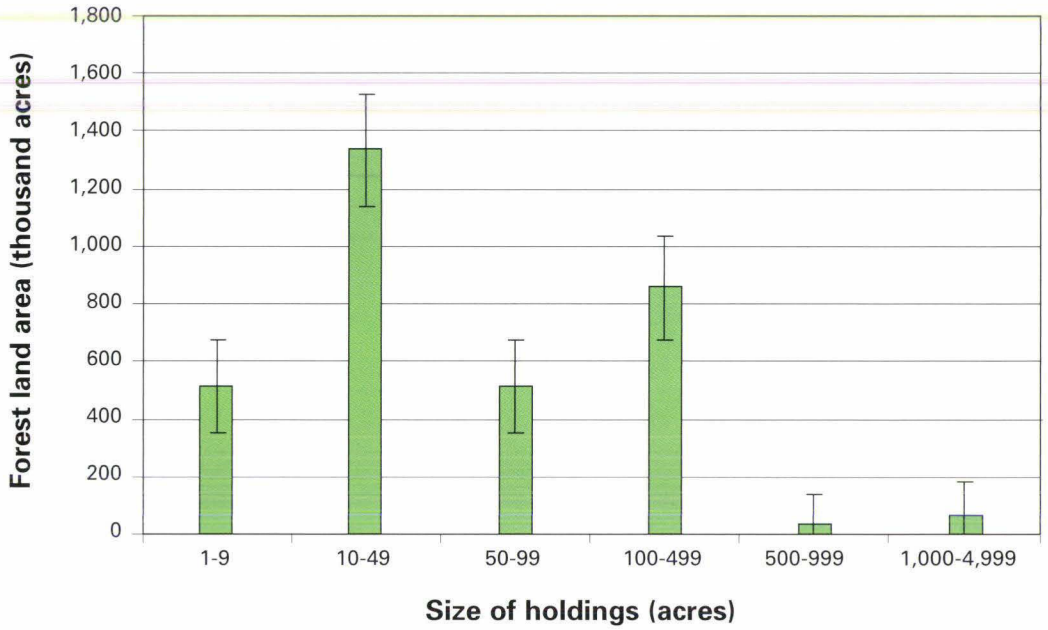
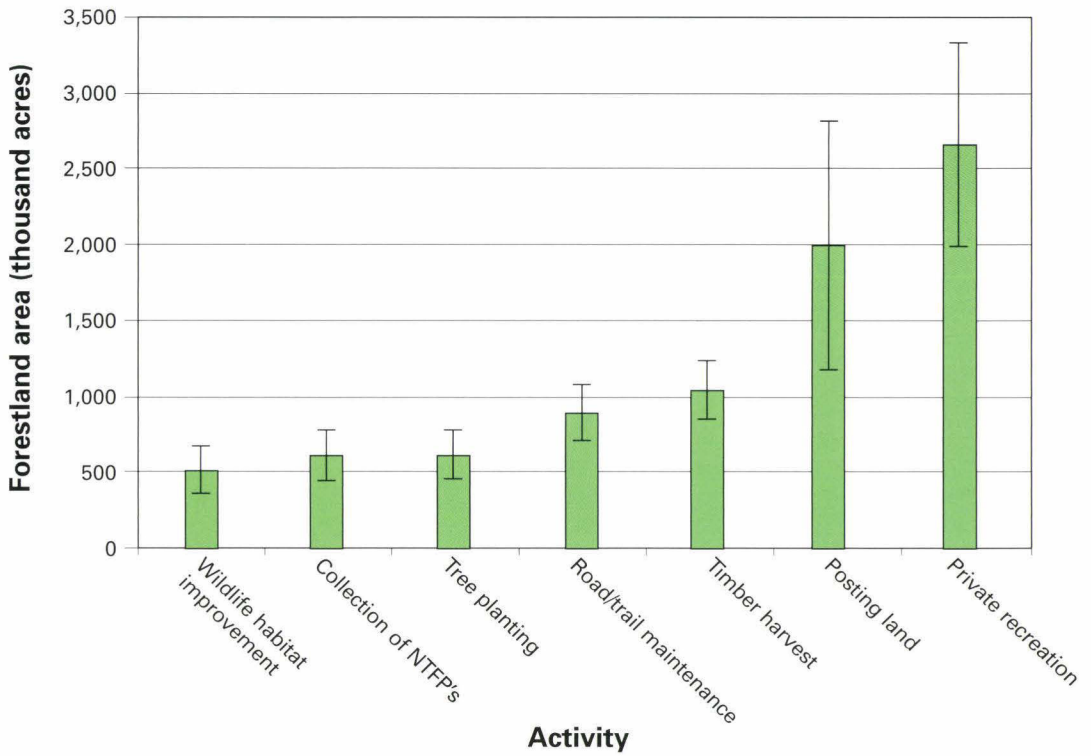


Figure 1.30. Area of family owned forests in Indiana by recent (past 5 years) forestry activity, 2003.



Urban Forests

Background:

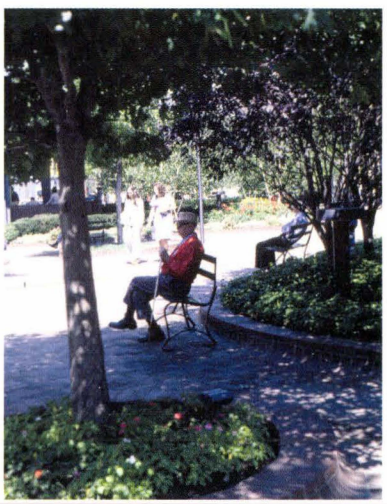
Urban forests (i.e., all trees within urban areas) have a significant impact on the environment and human population across Indiana, yet little is known about them. To aid understanding of this resource, we collected data as part of the USDA Forest Service's Urban Forest Health Monitoring Program. This program is designed to provide information on the composition, health, benefits, and values of urban forests and help detect any new problems (e.g., insect infestations) that may be affecting urban trees.

What We Found:

A pilot inventory of 32 field plots (identical to current phase 2 plots) was conducted within urban areas in Indiana during 2001-2002 (Nowak *et al.* 2004). Urban boundaries were delimited by the 1990 U.S. Census definition of urban and included all land uses (e.g., residential, park, forest, commercial). Thus, the inventory included trees in forested areas, such as urban parks, as well as street and backyard trees. While the information gathered from the pilot study is considered preliminary, it revealed that urban forests in Indiana are a significant resource that includes approximately 93 million trees greater than 1 inch in diameter. A little over half of the trees are small, less than 3 inches in diameter. The most common species in forest and nonforest urban areas were sassafras, silver maple, and eastern cottonwood (fig. 1.31), while the latter two species dominated in urban nonforest areas (i.e., street trees). Urban trees in Indiana improve air and water quality, help conserve energy, cool the air in summer, reduce ultraviolet (UV) radiation, enhance property values, and provide many other environmental and social benefits. Estimates indicate these trees have a total value (based on the cost of replacement or compensation to owners for tree loss) of about $56 billion (about $600 per tree) (fig. 1.32).

What This Means:

Urban trees in Indiana contribute to a healthy environment and benefit society in many ways. However, these trees face threats from land development, pollution, insects, and diseases. Monitoring their health will help sustain the vitality of this essential component of the Indiana's environments.



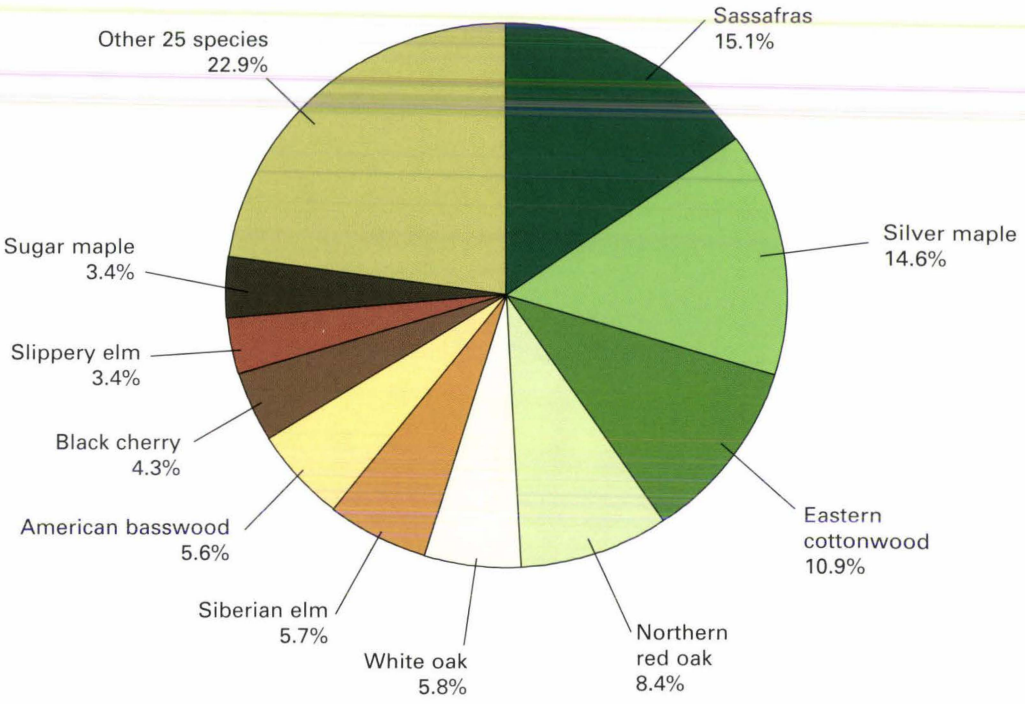


Figure 1.31. Overall species composition of Indiana's urban forests.

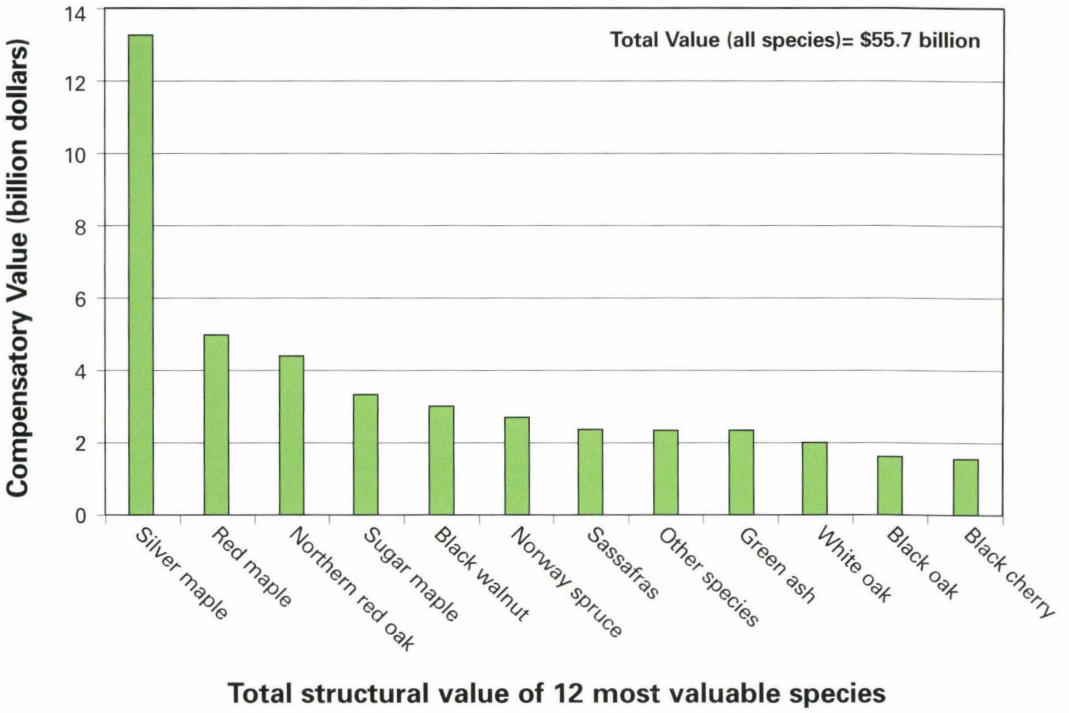


Figure 1.32. Estimated worth of the 12 most valuable species in Indiana's urban forests.

Forest Health

Forest Patterns

Background:

The fragmentation and urbanization of forest land areas has been identified as a major ecological issue in many states. Fragmentation is the process by which contiguous forest areas are subdivided into smaller forest tracts surrounded by nonforest land uses such as urban development or agriculture. The encroachment of development into forest areas has the potential to drastically alter the character and amount of interior forest throughout Indiana.

What We Found:

By applying techniques developed by Ritters *et al.* (2002) to National Land Cover dataset imagery (Vogelmann *et al.* 2001) for 1992 and 2001, we classified land in southern Indiana into five forest pattern groups: (1) interior forest (continuous forest canopy); (2) edge (junction between forest and nonforest areas); (3) perforated (nonforest patches in continuous forest areas); (4) patch (small forest area surrounded by nonforest); and (5) nonforest. This approach involved evaluating map pixels and assigning each one to one of the five classes. Based on this analysis, the percentage of interior forest increased from 14 percent in 1992 to 24 percent in 2001 (fig. 2.1). The amount of forest edge doubled, from 8 to 15 percent. The percentages of land classified as perforated, patch, and nonforest decreased between 1992 and 2001. Despite the overall increase in interior forest, some of the land classified as interior in 1992 became a part of a perforated landscape pattern in 2001. Forest interior areas increased primarily in forest land fringe areas in southwestern and southeastern Indiana (fig. 2.2). Most of the decline in interior forest took place in south-central Indiana, with forest inventory data indicating that about 70 percent of the lost interior areas were oak/hickory forests with total live tree volumes exceeding 1,000 cubic feet/acre.

What This Means:

Based on map pixel analysis, the area of interior forest in southern Indiana increased between 1992 and 2001. There is a healthy diversity of other forest landscape patterns ranging from edges to patches to perforated landscapes. Because a diversity of forest patterns benefits native flora and fauna, Indiana's current range of forest patterns may be considered beneficial. Although southern Indiana's total amount of interior forest increased between 1992 and 2001, some interior forest was lost in core areas. Most of the areas where interior forest was lost became a perforated landscape with nonforest patches dotting an otherwise continuous forest canopy. Because these areas tend to be moderate to higher volume oak/hickory stands, the question remains whether interior forest gains in southern Indiana will offset the negative effects of interior forest losses.

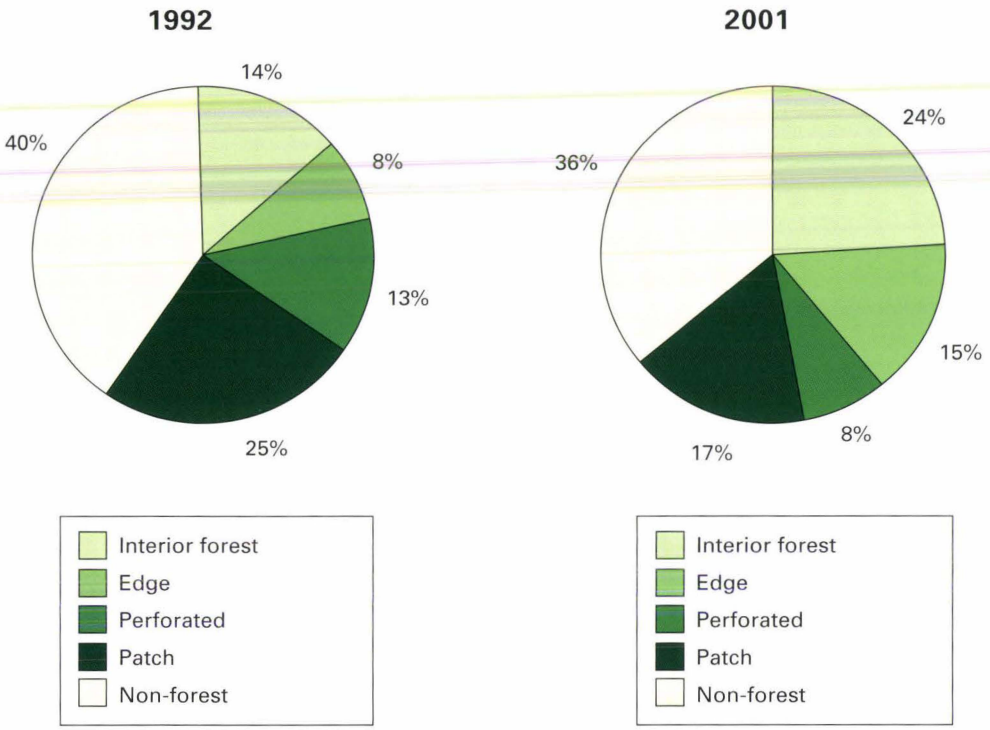


Figure 2.1. Distribution of landscape patterns derived from National Land Cover Dataset classification in southern Indiana for 1992 and 2001.

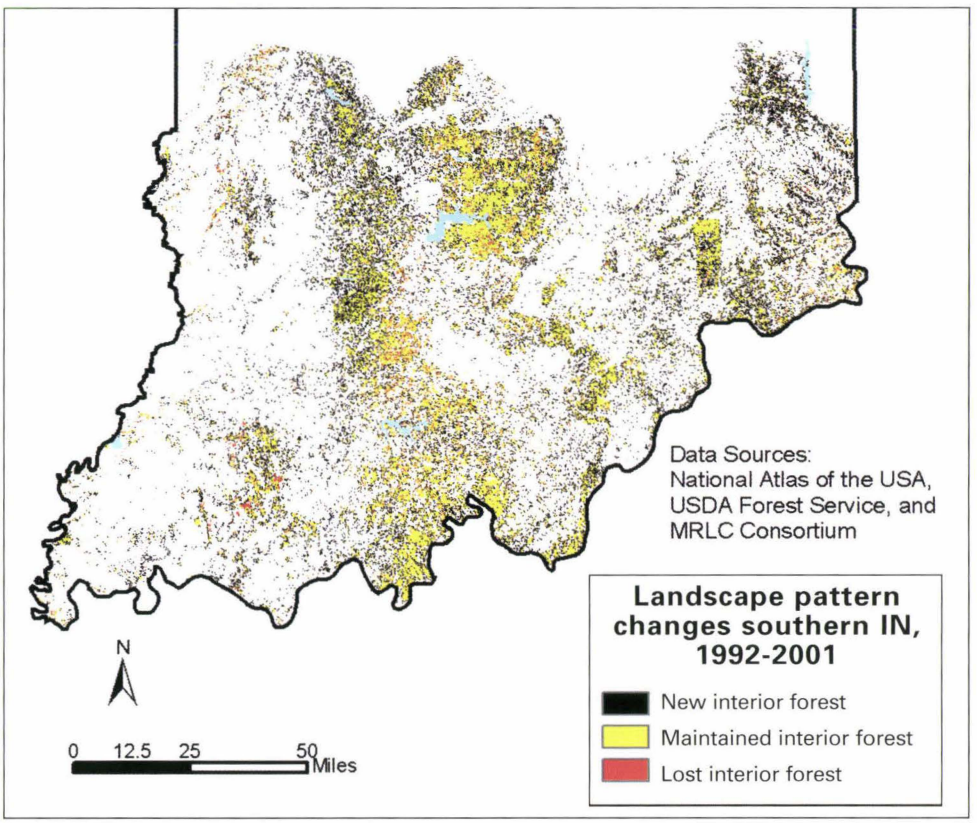


Figure 2.2. Changes in land area classified as interior forest in 1992 using National Land Cover Dataset classification, southern Indiana, 1992-2001.

Crowns

Background:

The overall condition of the tree crowns indicates the health status of a forest stand. For example, a forest suffering from disease will have low crown ratios, high transparency, low density, and obvious dieback.

What We Found:

Although no tree species in Indiana's forests displayed obvious poor crown health conditions, some trends should be noted. While soft maples and other red oaks displayed the highest mean crown dieback (recently dead twigs as percent of live crown) (fig. 2.3), they also had some of the highest uncompacted crown ratios (percent of crown length versus total tree length) (nearing or exceeding 60 percent). White and red oaks had some of the highest mean crown transparencies (amount of light that passes through tree crown), followed by ash (fig. 2.4). The average healthy hardwood tree transparency is between 15-20 percent. All major tree species in Indiana fell well within this range. The spatial distributions of crown dieback indicated few substantive hotspots of declining tree crown health.

What This Means:

Although crown conditions are sampled on a relatively small subset of forest inventory plots, no major health decline in crown conditions appeared across Indiana. However, crown transparencies were highest for oaks, most likely a result of the advanced age of oak forests across Indiana. The fragmented forests of northern Indiana show some crown dieback, since stands often exist in forest edges subjected to wind damage and other stress. Drought most certainly plays a role in tree crown health. Unfortunately, the impact of drought is best analyzed with crown trend data that are unavailable at this point. Overall, tree crown conditions across Indiana indicate robust forest health.

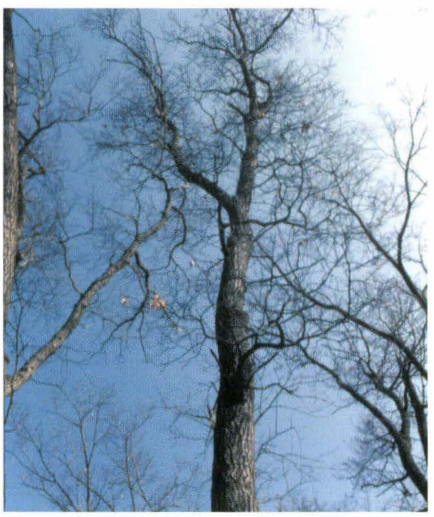


Figure 2.3. Mean crown ratio and crown dieback for selected species groups, Indiana, 1999-2003.

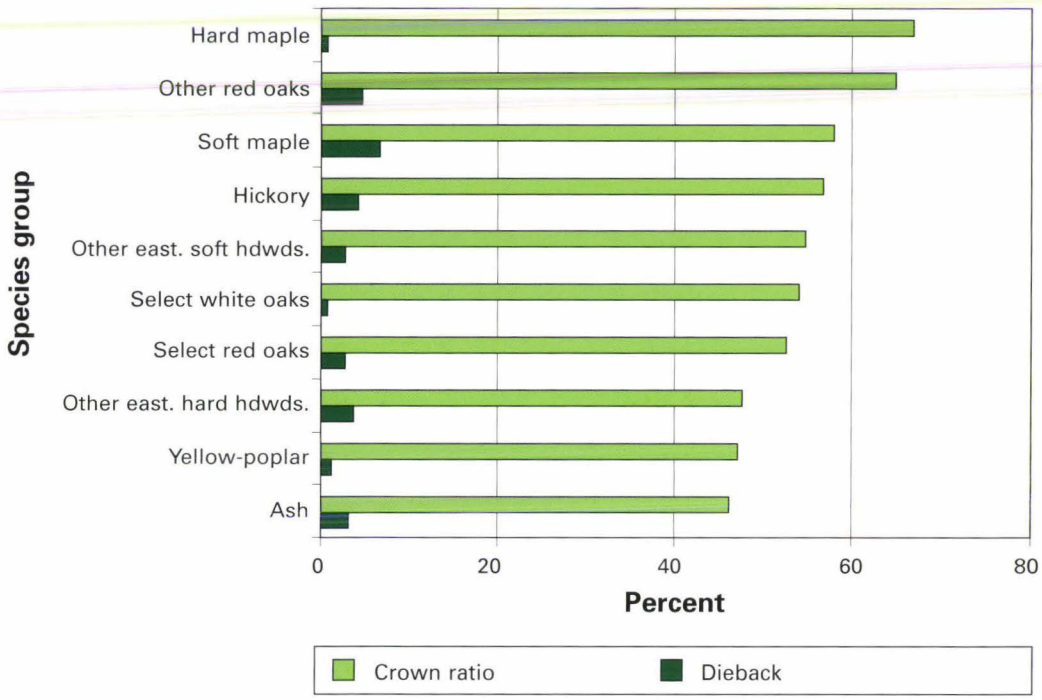
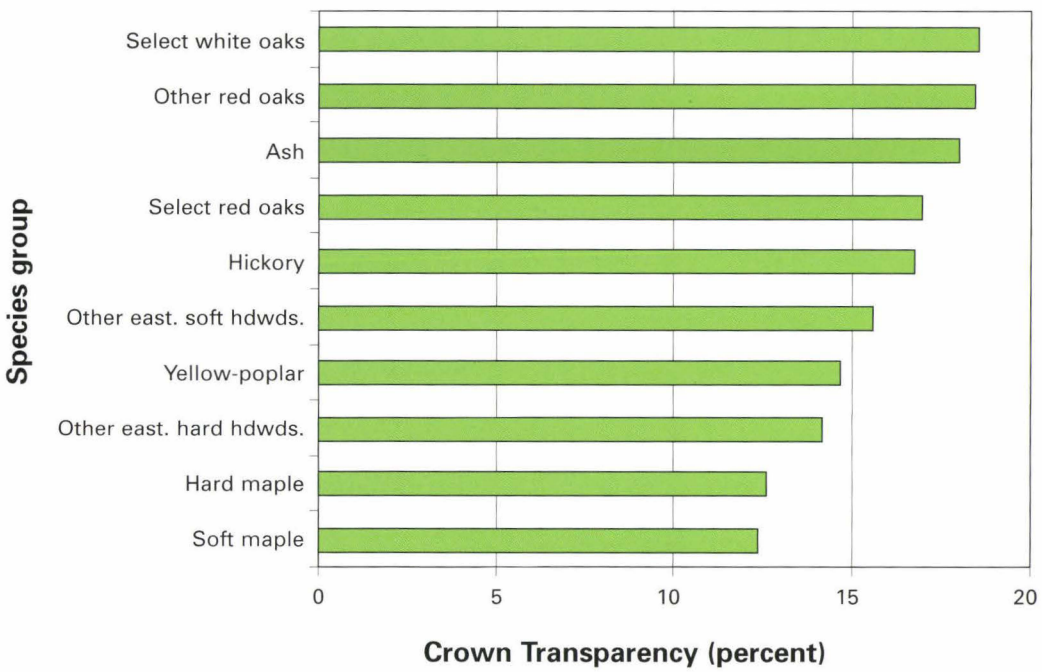
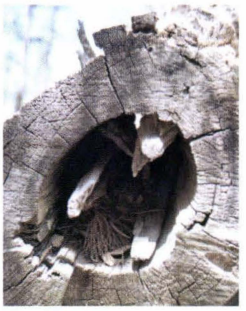


Figure 2.4. Mean crown transparency for selected species groups, Indiana, 1999-2003.



Ground Truth: Down Woody Debris



Background:

Down woody debris in the form of fallen trees, branches, litterfall, and duff plays a critical role in Indiana's forests. This material provides valuable wildlife habitat, helps determine forest fire behavior, and constitutes an important carbon sink.

What We Found:

The mean forest fuel loading across the State is about 20 tons/acre, an amount that does not pose significant fire risk given the mesic conditions in Indiana's forests (fig. 2.5). The 1,000-hr fuels, otherwise termed coarse woody debris, have mean fuel loadings of nearly 7 tons/acre, while duff averages more than 6 tons/acre and litter averages nearly 4 tons/acre. The fine woody fuels (1-hr, 10-hr, and 100-hr) added together are below 2 tons/acre across all forest types. Most coarse woody debris in Indiana is small and in advanced stages of decay (fig. 2.6), with over two-thirds less than 8 inches in diameter (fig. 2.6a). More than half of this material is in the latter stages of decay (fig. 2.6b). The distribution of fine woody fuels varies widely, with no discernible pattern evident (fig. 2.7). Total tonnages are highest in the heavily forested areas of south-central Indiana (fig. 2.8).

What This Means:

Current fuel loadings across Indiana do not pose a significant fire risk. Indiana's average fuel loading of 20 tons/acre is well below the 50 tons or more found in some states. Due to the predominance of hardwoods, Indiana has an appreciable amount of litterfall (almost 4 tons/acre), while fine woody debris is limited. Fuel loadings appear to be highest in the southeastern part of the State. The wildlife habitat provided by coarse woody debris is minimal due to lack of large pieces and advanced stages of decay. Although a diversity of sizes provides optimal habitat for a range of species, the lack of large pieces is detrimental to larger wildlife species that use them for shelter and cover.

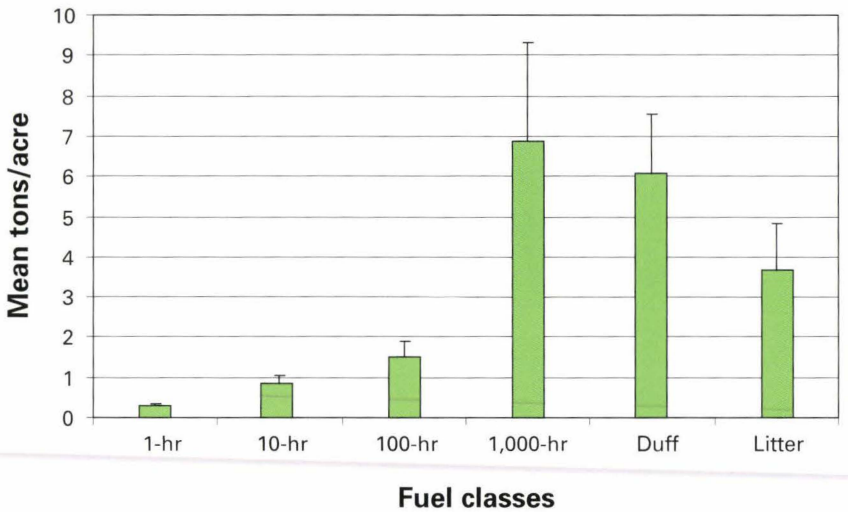


Figure 2.5. Distribution of fuel classes and associated standard errors for fuel hour classes, Indiana, 2001-2003.

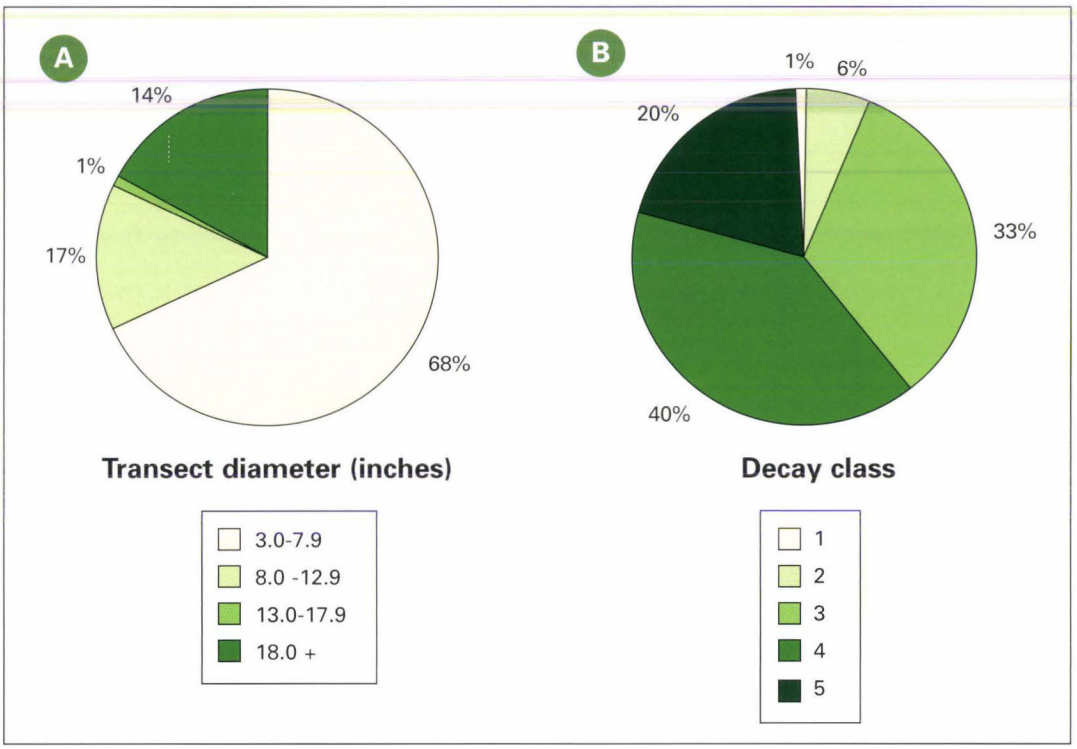


Figure 2.6. Proportions of coarse woody debris pieces per acre by transect diameter (A) and decay class (B) (1=least decayed, 5=most decayed), Indiana, 2001-2003.

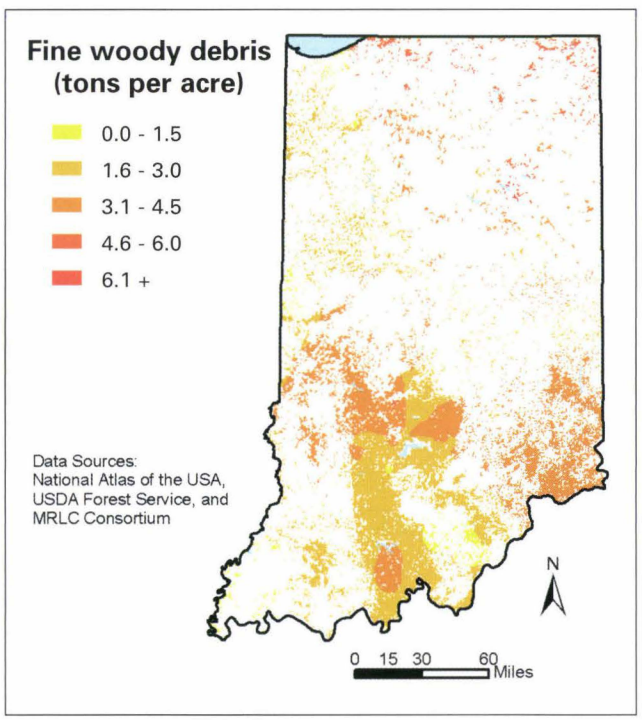


Figure 2.7. Distribution of fine woody debris across Indiana (inverse distance weighting interpolation), 2001-2003.

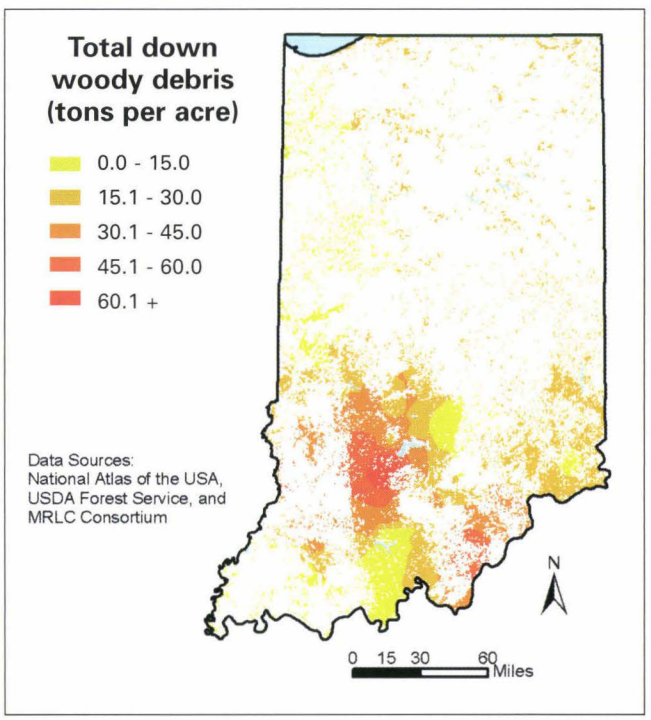


Figure 2.8. Distribution of total down woody debris (fine, coarse, duff, and litter) across Indiana (inverse distance weighting interpolation), 2001-2003.

Ozone Damage

Background:

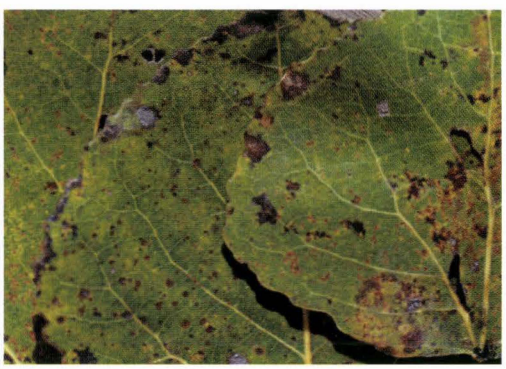
Ground level ozone exposure is injuring the foliage of sensitive understory and canopy trees in Indiana, potentially affecting the long-term productivity of ozone-sensitive native species. Given this fact, it would be prudent to use ozone exposure and foliar injury scores in assessing trends in forest productivity and composition.

What We Found:

Indiana's ozone exposures are consistently the highest in the north central region and are relatively high compared with many states in the Nation (fig. 2.9). The State's central and southern forests, in particular, are subject to elevated ozone levels. Not surprisingly, Indiana also has the greatest number of plants exhibiting ozone injury of all north central states (fig. 2.10). Surveys indicate leaf damage on more than 25 percent of all evaluated indicator plants in certain years. Over the 5-year survey period (1997-2001), about 10 percent of all evaluated plants showed visible injury. Ozone damage was not equally distributed among indicator species; understory species suffered greater injury (9.6 percent of plants surveyed) than trees (approximately 5 percent of trees surveyed). Among tree species, yellow-poplar displayed greater ozone injury across the State than white ash and black cherry. Plant responses to ground level ozone exposures differ over time and space due to climatic, site quality, and genetic variables. An injury index is calculated by aggregating individual species injury scores to create one score for the entire biosite. An injury map based on biosite injury scores (fig. 2.11) indicates foliar injury is greatest in southern and central Indiana, roughly corresponding with the areas of greatest contiguous forest and highest ozone exposure (fig. 2.9).

What This Means:

Relatively high ozone exposure in Indiana's forests is adversely affecting trees and other plants. Between 1997 and 2001, almost 10 percent of ozone-sensitive species displayed damage. The effects of ozone stress should be less severe on the most common tree species, such as maples and oaks, since they are relatively tolerant of ozone. However, given the current ozone exposures and evidence of widespread foliar injury, the potential exists for reduced tree growth and compromised forest health across Indiana.



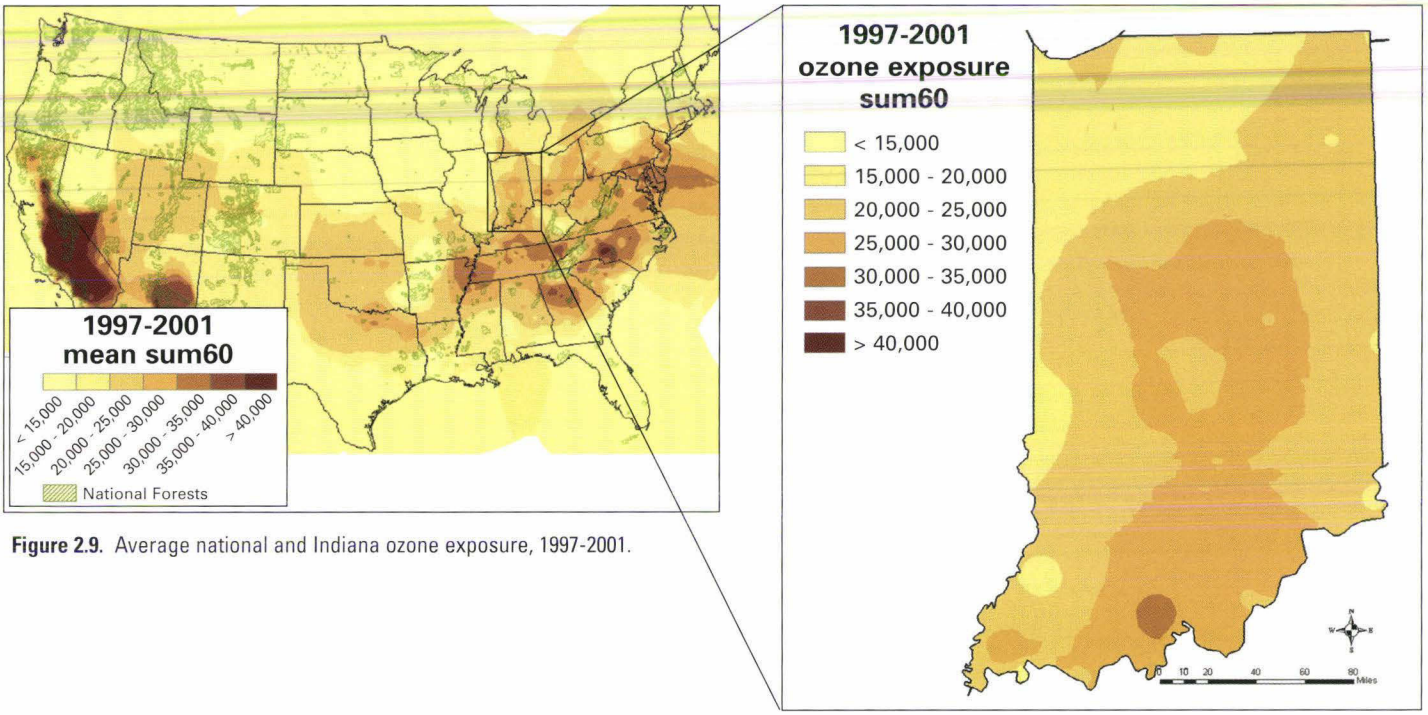


Figure 2.9. Average national and Indiana ozone exposure, 1997-2001.

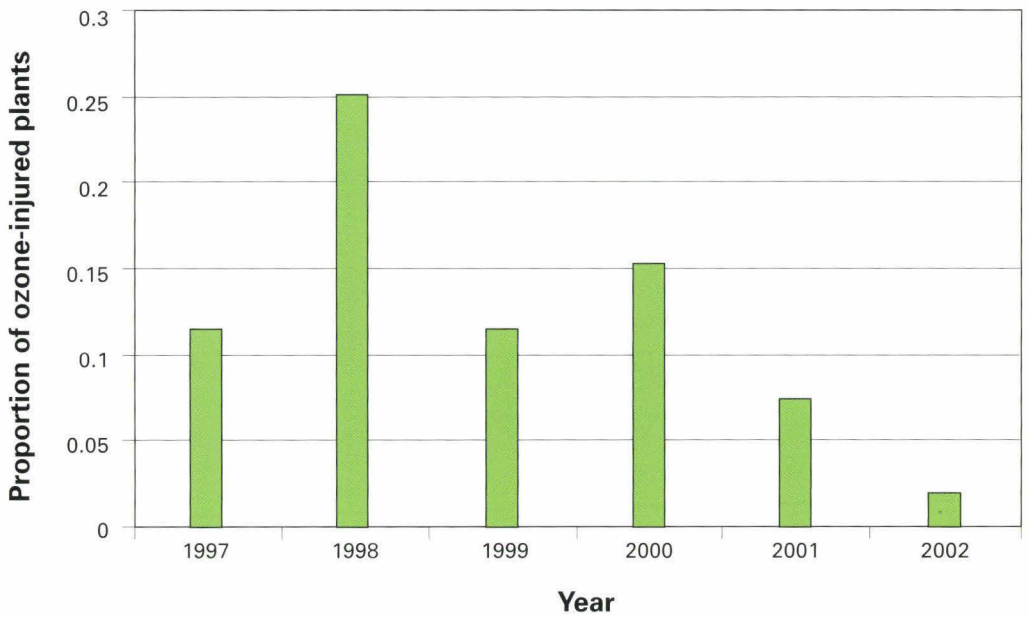
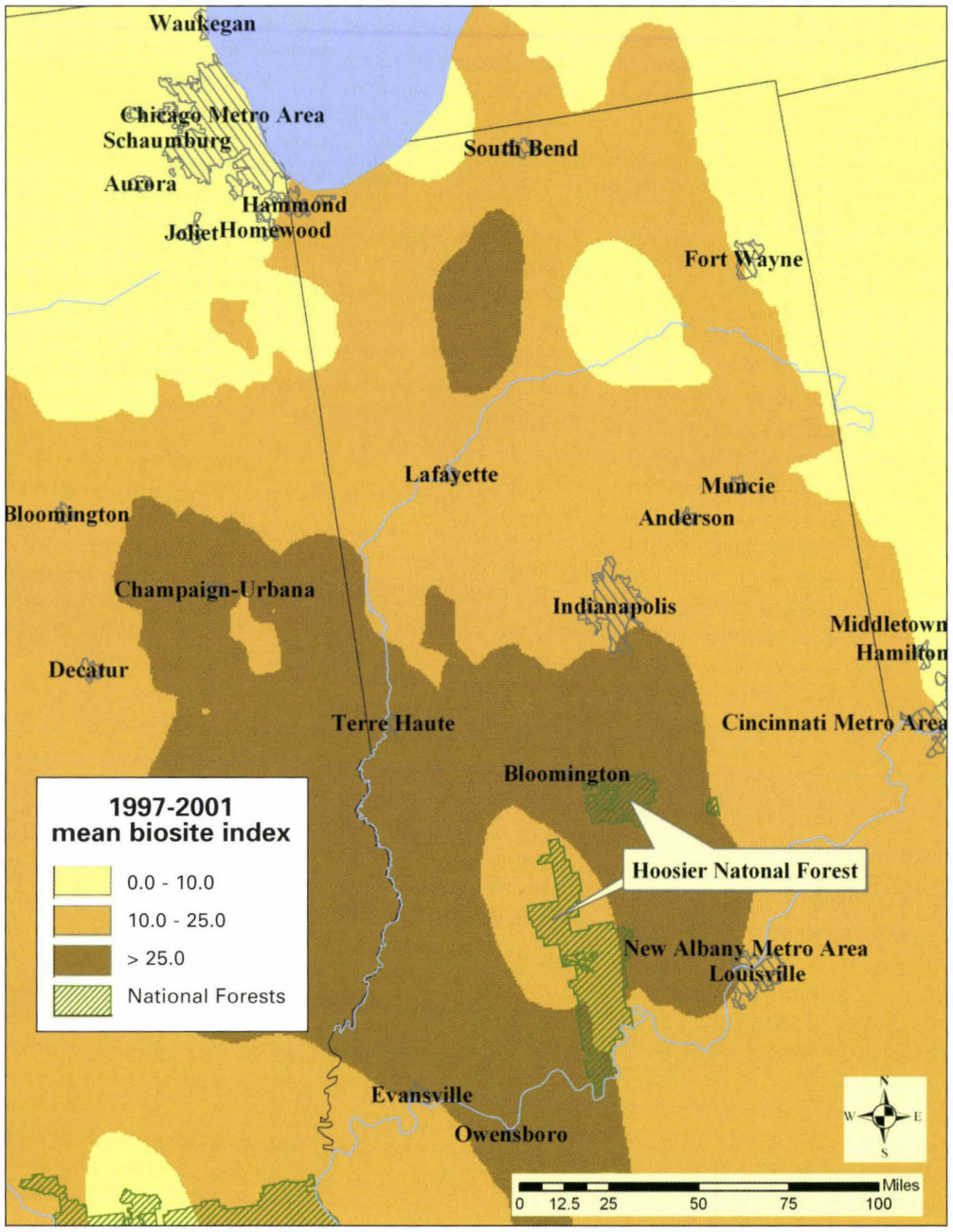


Figure 2.10. Proportion of evaluated plants displaying ozone injury by inventory year, Indiana, 1997-2002.

Figure 2.11. Estimated plant injury due to ozone exposure based on biosite index.



A Healthy Mix: Vegetation Diversity

Background:

The diversity and abundance of vascular plant species (possessing water- and sap-conducting tissues) are important indicators of forest ecosystem health. The total species composition of forest stands often reflects chronic stresses such as site degradation, climate change, and pollution. Such disturbances may lead to an increase in opportunistic species, including nonnative or invasive species.

What We Found:

We surveyed all vascular forest plant species on 25 sample plots between 2001 and 2003. The majority of plots had more than 31 species in their respective forest stands, while 11 plots had more than 40 species (fig. 2.12). The most abundant understory plants were in the genus *Parthenocissus,* followed by *Rosa, Toxicodendron,* and *Sanicula* (fig. 2.13), with most plots having at least one of these genera present. The number of vascular species per plot and total basal area of trees on the plot were only weakly correlated (fig. 2.14).

What This Means:

Indiana's forests support a multitude of vascular plant species. Nearly all inventory plots had at least a dozen species, while a few of the vegetative diversity plots had more than three dozen. The weak relationship between density (stand basal area) and the number of vascular species indicates that maturing stands may have more diverse understories. Because the vegetative diversity inventory only began in 2001, trends are difficult to ascertain at this time. However, future plant diversity inventories may reveal more about the impacts of forest fragmentation and invasive species.

Figure 2.12. Understory vascular plant diversity in Indiana's forests, 2001-2003.

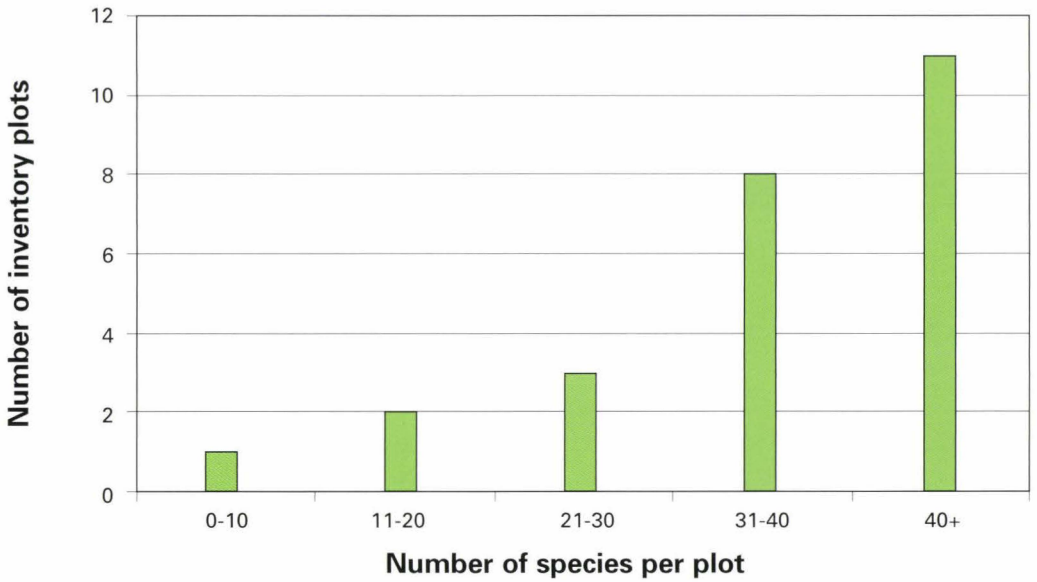


Figure 2.13. Distribution of understory species on all inventory plots (n=25), Indiana, 2001-2003.

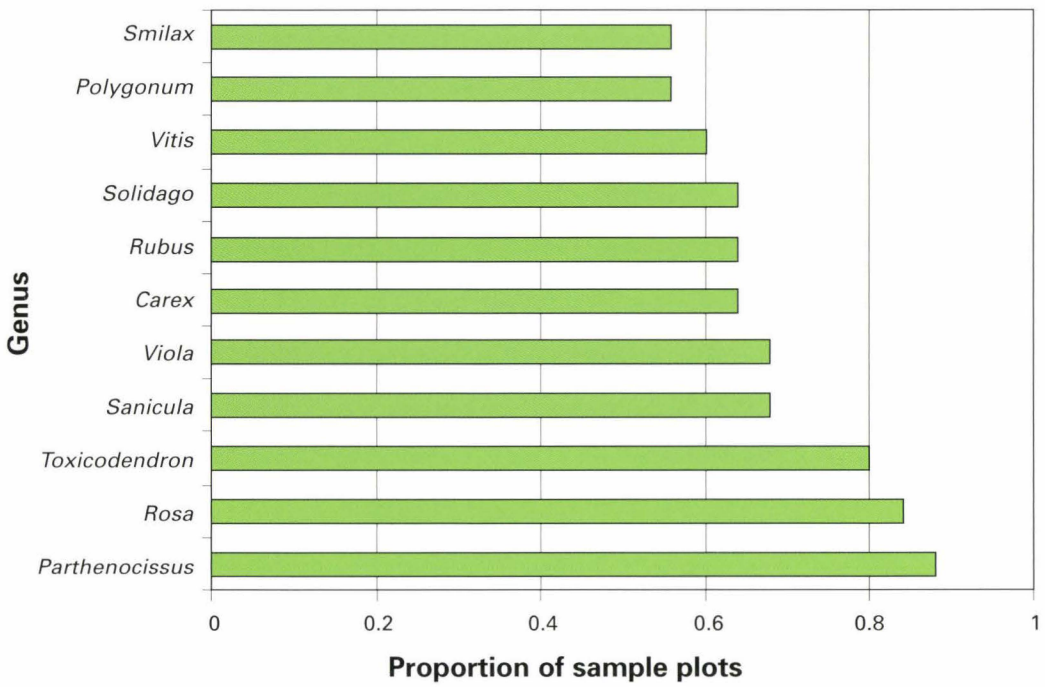
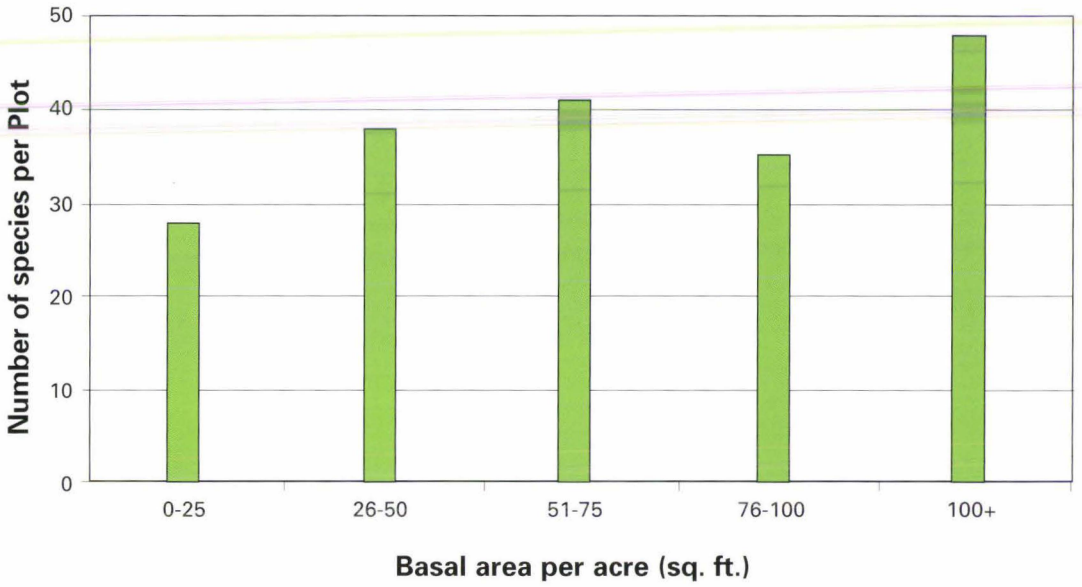


Figure 2.14. Mean number of vascular plant species by stand basal area class, Indiana, 2001-2003.



Forest Invaders

Background:

Introduced and invasive species can be detrimental to native forest ecosystems. Invasive species may displace native vegetation, sometimes dominating ecological niches previously occupied by native species, and reduce forest ecosystem diversity, resiliency, and wildlife habitat.

What We Found:

Forest inventory data from approximately 1,000 tree plots and 25 vegetative diversity plots were used to assess the prevalence of introduced and invasive plant species. Most of the 25 plots we surveyed for vegetative diversity had at least one invasive or introduced species (http://ncrs.fs.fed.us/4801/regional-programs/Inventory/fieldcrews/manuals/) (fig. 2.15). However, the majority of plots had two or fewer invasive or introduced species, while only one plot had more than eight. The most prevalent invasive species was multiflora rose (*Rosa multiflora*), which occurred on over two-thirds of sample plots (fig. 2.16). The second most common invasive species was Japanese honeysuckle (*Lonicera japonica*), which was present on 6 of 25 plots. The number of invasive or introduced species in the forest understory appeared to be directly related to stand density. Stands that had more than 100 sq. ft. of basal area averaged less than two invasive/introduced species, while those that had 25 sq. ft. or less of basal area averaged more than four (fig. 2.17). The most common introduced tree species appearing in the overstory was tree-of-heaven (*Ailanthus altissima*), but it was found only on plots near the Chicago area of northern Indiana and in forests along the Ohio River in southern Indiana (fig. 2.18).

What This Means:

While invasive or introduced plant species exist in most of Indiana's forests, their potential for harm is difficult to assess. Multiflora rose was present on a majority of plots surveyed, while dozens of other species were found scattered across the plots. Invasive or introduced species were most likely to occur on recently disturbed sites or nonforest forest boundary areas where low stand densities favor establishment of new species. Tree-of-heaven occupies the overstory of some stands along a corridor defined by the Ohio River, where it is regenerating and thriving. Although this and other invasive and introduced species may represent only a minority of species in Indiana's diverse forest ecosystems, potentially they may displace native species and negatively affect the health of Indiana's forests.

Figure 2.15. Distribution of invasive or introduced understory species observed on vegetative diversity plots (n=25), Indiana, 2001-2003.

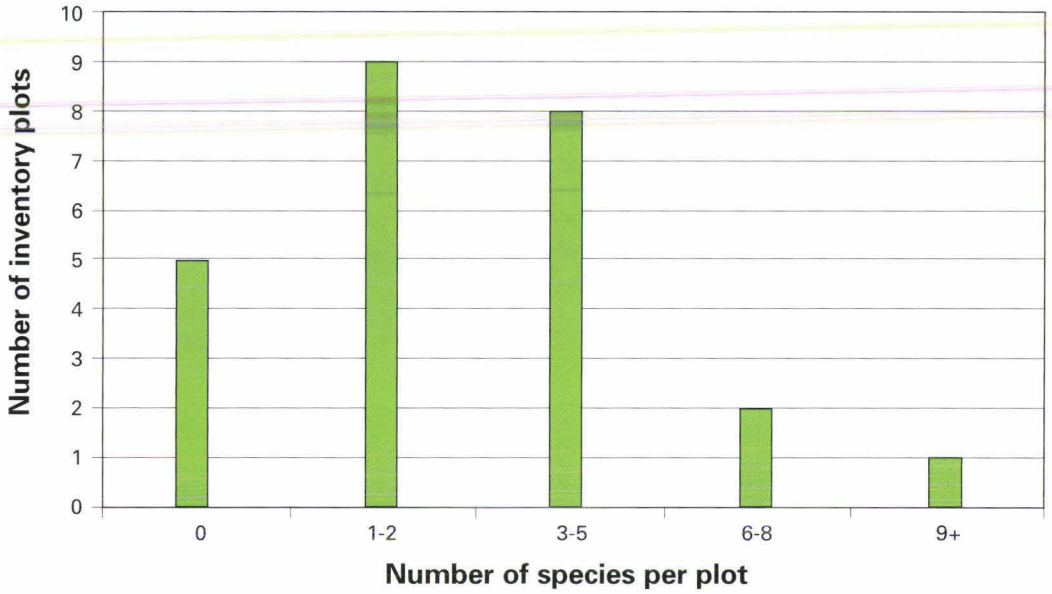


Figure 2.16. Occurrence of invasive or introduced understory species on vegetative diversity plots (n=25), Indiana, 2001-2003.

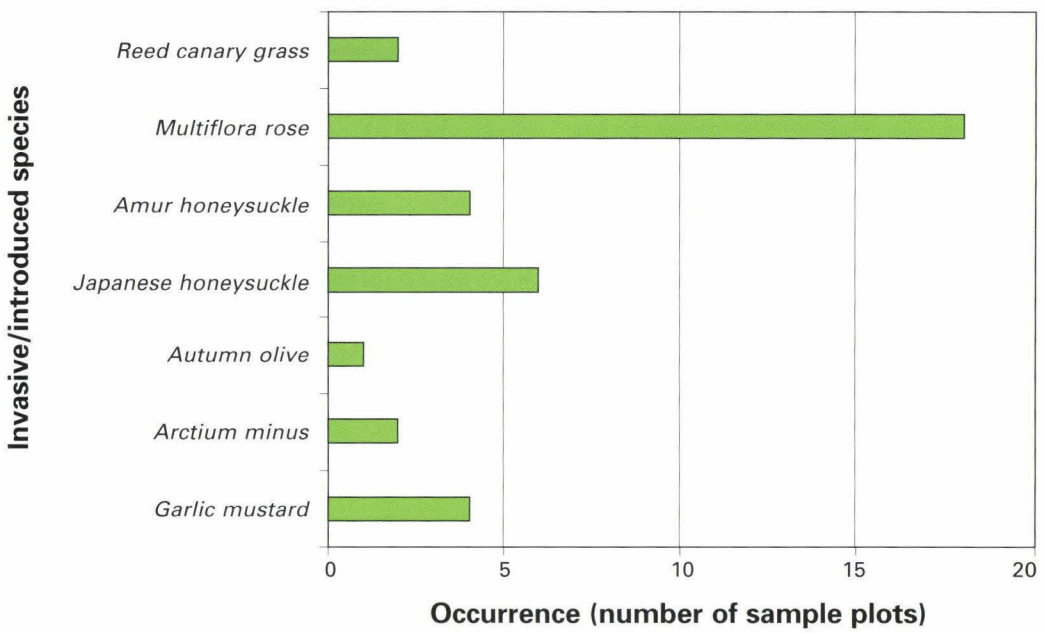


Figure 2.17. Mean number of understory invasive or introduced species by stand basal area class on vegetative diversity plots (n=25), Indiana, 2001-2003.

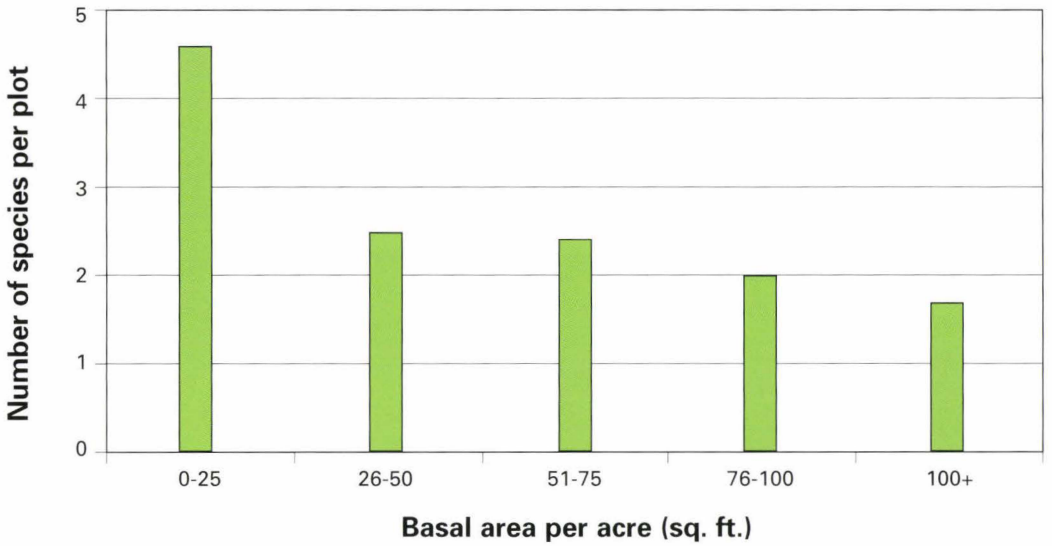
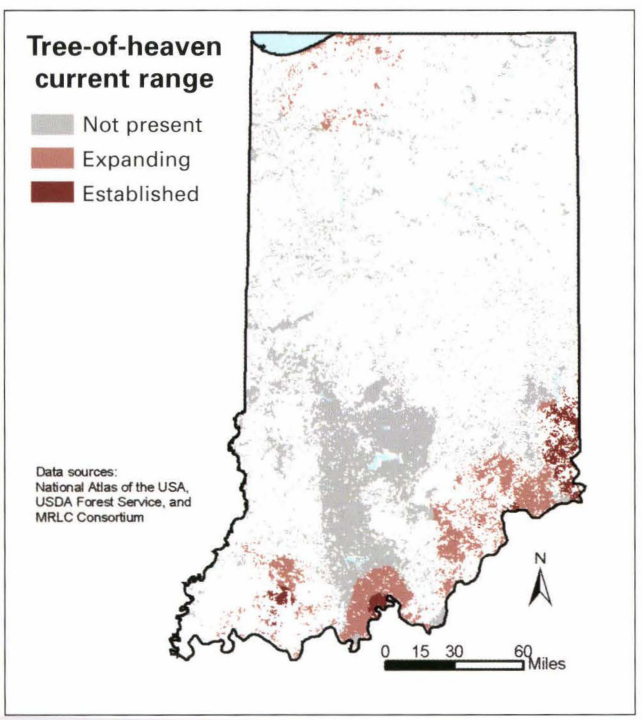


Figure 2.18. Distribution of tree-of-heaven (*Ailanthus altissima*) in Indiana's forests based on inverse distance weighting interpolation of plot data, 1999-2003.



Wildlife Habitat

Background:

Indiana's forests support wildlife species of concern, such as the Indiana bat, as well as important game animals like the white-tailed deer. Describing the condition of forest wildlife habitat across Indiana may identify areas currently lacking adequate habitat while establishing a baseline for future monitoring efforts. Mature forests, coarse woody debris, snags, and forest spatial patterns are all important descriptors of forest wildlife habitat.

What We Found:

Diverse stages of stand development are found across the forests of Indiana (fig. 2.19). Generally, more mature forests (based on mean tree size and stand density assessments) are found in the south-central areas, whereas younger stands are more typically found in the far southern and southeastern areas. Snags (standing dead trees) vary in numbers across the State, although they appear more abundant in the south-central forests (fig. 2.20). The south-central forests also contain the largest quantities of coarse woody debris (fig. 2.21). Indiana forests today are highly fragmented (fig. 2.22). Most of the State is covered by the remnants of once-continuous forest cover, while islands of interior forest are fringed by edges and perforated with nonforest patches (for more details on imagery classification see the *Forest Patterns* section).

What This Means:

Current inventory data indicate diverse and abundant forest habitat (snags, coarse woody debris, and forest patterns) to support numerous wildlife species across Indiana. However, data are insufficient to project trends or draw conclusions about individual wildlife species. The fact that mature forests are widely dispersed and increasing across Indiana bodes well for species that depend on continuous cover. Continued forest fragmentation will favor species that require a combination of mature forest and nonforest areas for foraging. Overall, native wildlife habitat exists across Indiana in varying amounts.

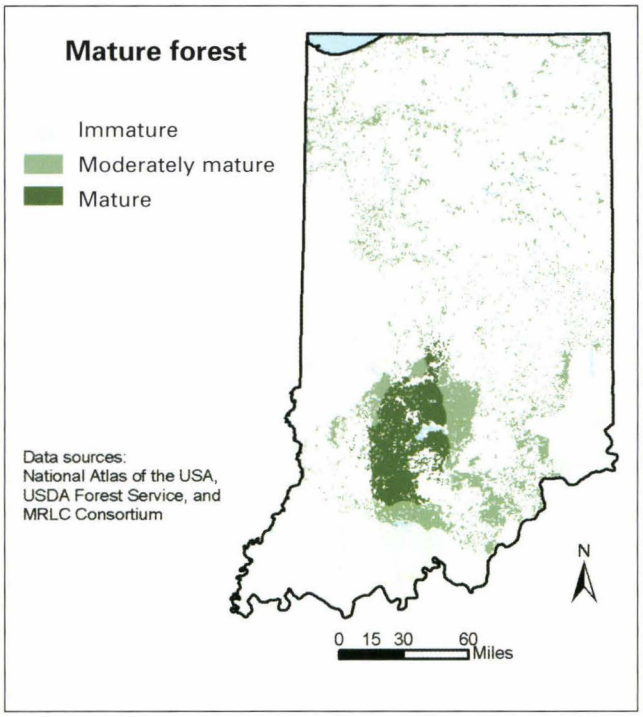


Figure 2.19. Maturity of Indiana's forests in terms of stand density and average tree size (inverse distance weighting interpolation), 1999-2003.

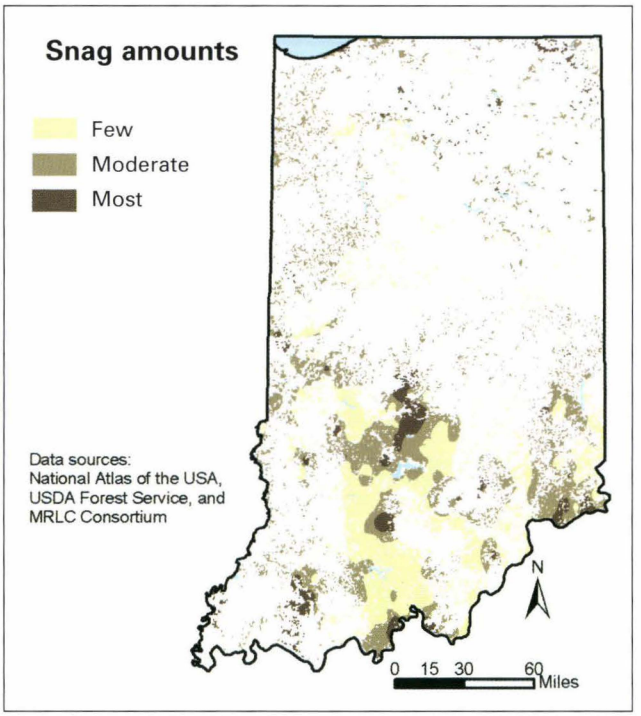


Figure 2.20. Amounts of snag habitat found across Indiana's forestland based on snag density assessment (inverse distance weighting interpolation), 1999-2003.

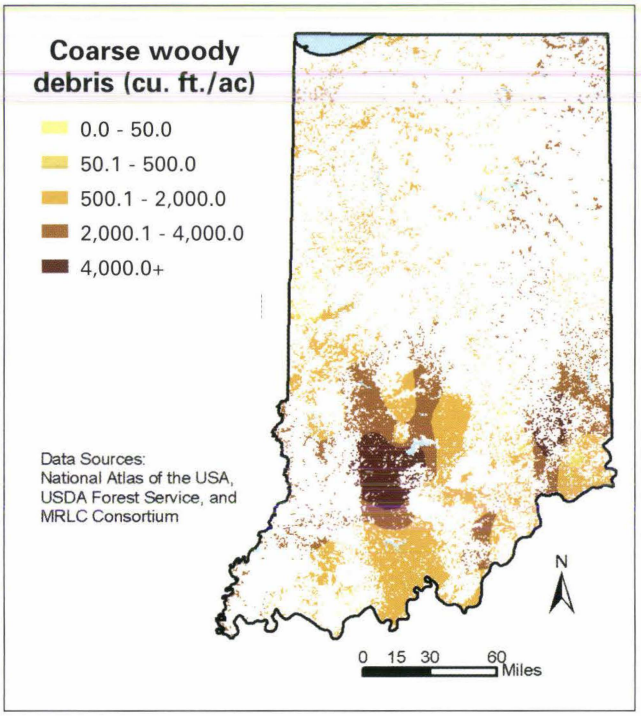


Figure 2.21. Distribution of coarse woody debris across Indiana (inverse distance weighting interpolation), 2001-2003.

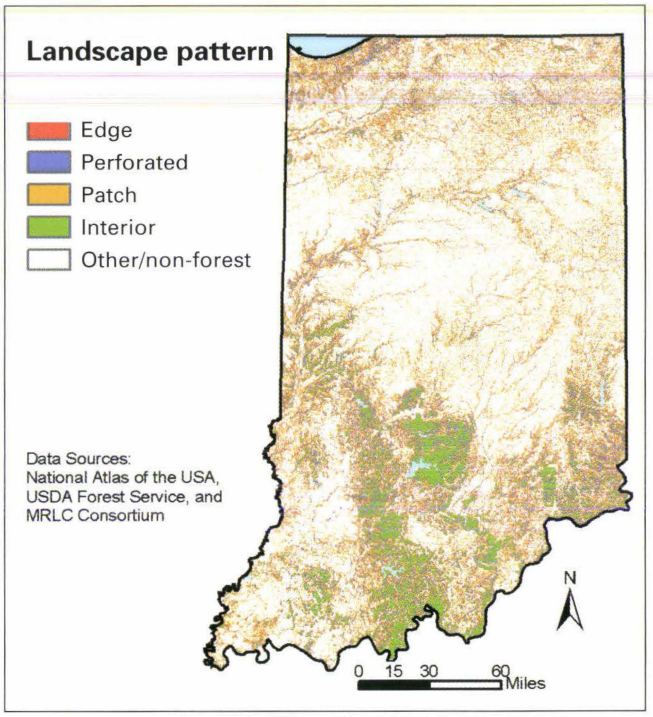
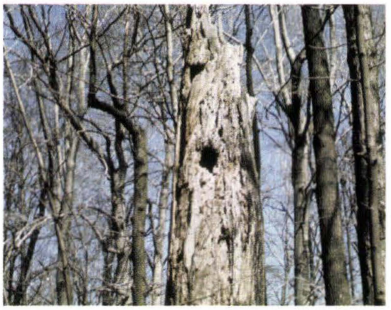


Figure 2.22. Distribution of forest edge, interior forest, perforated forest, forest patches, and non-forest according to classified NLCD imagery, 1992.

Snags



Background:

Standing dead trees (snags) are important indicators of wildlife habitat, structural diversity, past mortality events, and carbon storage. The number and density of such trees, together with decay classes, species, and sizes, define the snag resource across Indiana's forests.

What We Found:

Between 1999 and 2003, we collected data on 1,502 standing dead trees of numerous species and sizes in varying stages of decay. The "other soft hardwoods" (primarily American elm, sassafras, and slippery elm) made up nearly 41 percent of all snags surveyed (American elm made up 32 percent of this species group) (fig. 2.23). The majority of standing dead trees were between 5 and 8 inches in d.b.h. (fig. 2.24). Snags in this size grouping tended to have less advanced decay than those in larger size classes. Additionally, snags in the "other eastern soft hardwoods" group had the highest basal area (nearly 2 square feet per acre, with American elm contributing nearly 40 percent), followed by "other red oaks" and "other eastern hard hardwoods" (mean basal areas around 0.5 square feet per acre) (fig. 2.25).

What This Means:

American elm contributes the most to Indiana's snag population, both in terms of absolute numbers and basal area. Most of these snags are relatively small in size and result from both the presence of tree disease (primarily Dutch elm disease) and maturing forests across Indiana. The majority of sassafras trees died from unknown reasons, although sassafras is subject to *Nectria* canker, a fungal disease that can be fatal. Additionally, sassafras is a shade-intolerant species and may suffer from competition after being overtopped in developing forest stands. As forest stands continue to mature, smaller trees and certain early-successional species will suffer competition-induced mortality, resulting in further accumulation of small snags. In terms of wildlife habitat, it appears there will be sufficient numbers of recently deceased trees to replace fully decayed snags as Indiana's stands develop.

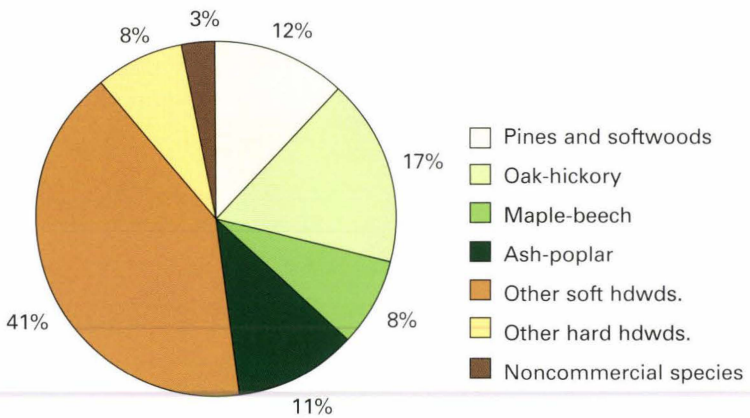


Figure 2.23. Species group composition of standing dead trees (snags), Indiana, 1999-2003.

Figure 2.24. Distribution of standing dead trees by decay and diameter classes for all dead trees inventoried, Indiana, 1999-2003 (decay class 1=least decayed, decay class 5=most decayed).

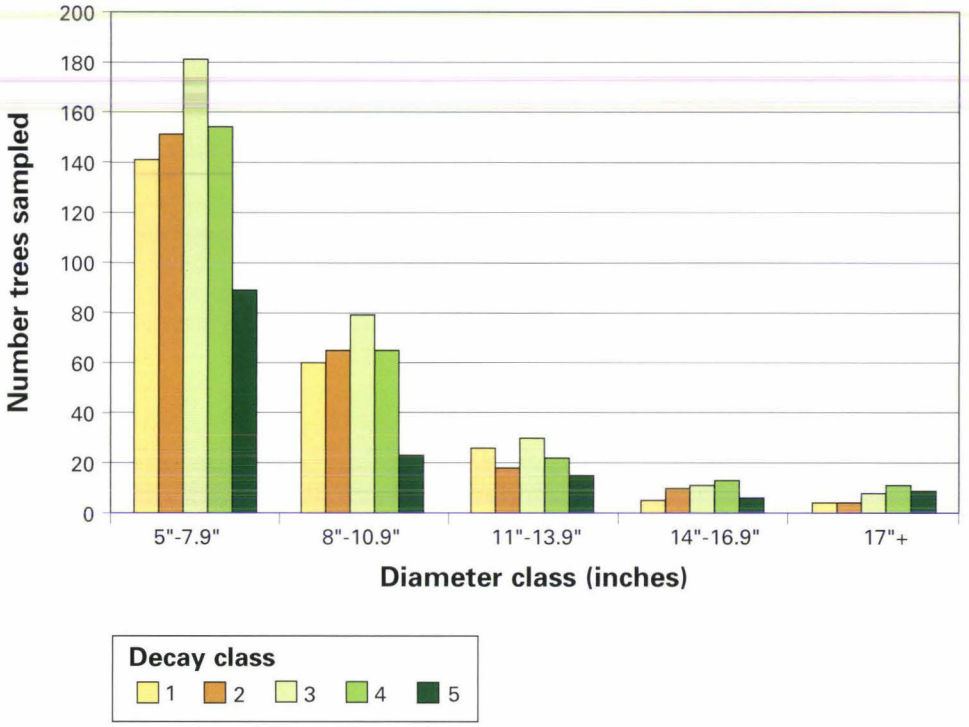
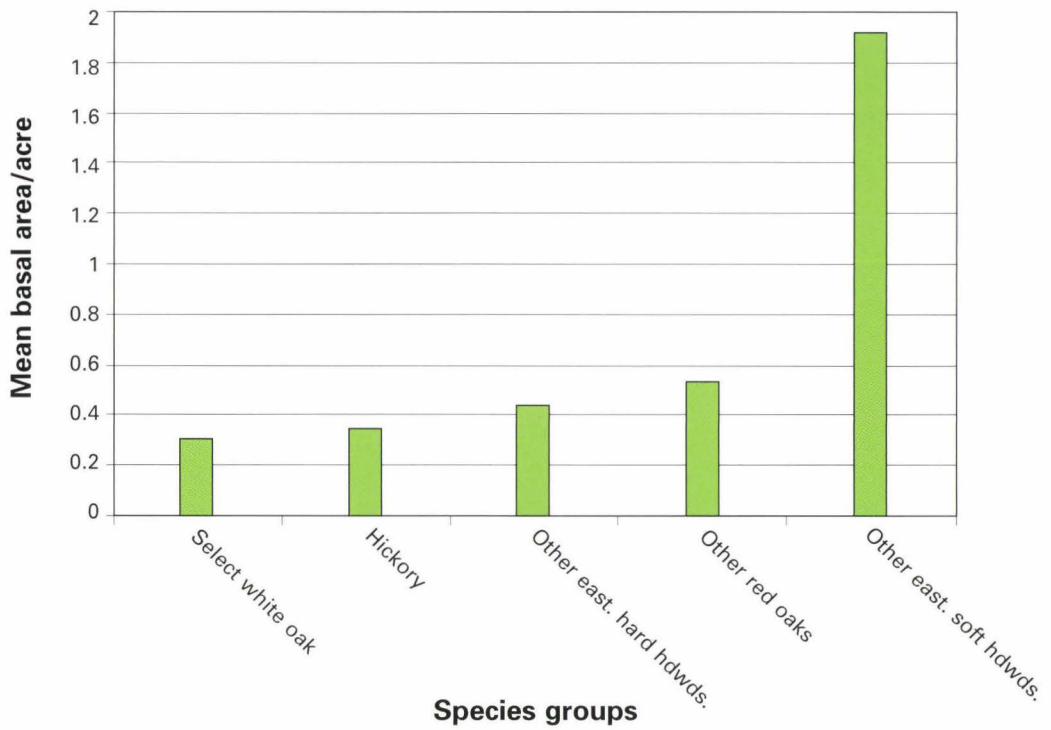


Figure 2.25. Basal area of the five most common standing dead tree species groups, Indiana, 1999-2003.



Soils

Background:

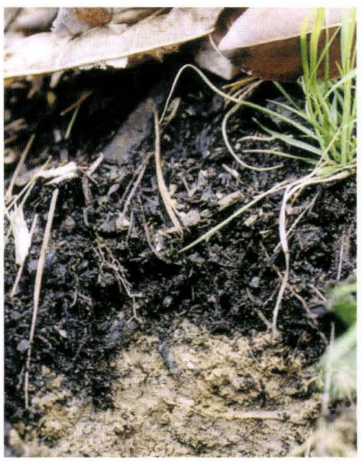
Rich soils are the foundation of productive forest land. Soil quality depends on geologic history as well as vegetation patterns, moisture regimes, and land uses. Northern Indiana was glaciated during the last ice age, positively affecting the soils there, while southern Indiana was largely unglaciated.

What We Found:

The forests of southern Indiana are largely underlain by inceptisols, while those in the north are underlain by alfisols (fig. 2.26). Inceptisols are relatively young soils with few or weakly developed diagnostic features, and alfisols are fertile soils generally possessing a subsurface layer enriched with clay and a medium to high base saturation. As a result, the forest lands of northern Indiana are generally of higher quality than those in the south. Elm/ash/cottonwood forests are found on the highest quality soils in the northern areas of the State, where mineral soils have relatively high amounts of nitrogen, phosphorous, potassium, and a good cation exchange capacity. Based on a soil quality index (SQI) combining distinct physical and chemical soil properties, the primary forest lands of southern Indiana are generally below average in quality with respect to both the State and region (fig. 2.27). The southern forests also store less carbon in the soil than the forest fragments in the northern part of the State (fig. 2.28).

What This Means:

There are at least two explanations for the superior soil status of forests of northern Indiana. First, the northern forests are largely underlain by alfisols, while the southern forests frequently occur on lower quality inceptisols. Second, northern forests more commonly occupy riparian or nonagricultural areas where nutrients are replenished by occasional flooding. Wet soils accumulate carbon more readily than drier sites. Further, the elm/ash/cottonwood forest types commonly found in northern Indiana produce litter layers that decompose quickly, resulting in more fertile soils than found in other forest types (e.g., oak/hickory). Elm and ash leaves typically decay quickly, while oak leaves decay at slower rates (Pritchett and Fisher 1987). Leaf decay is accelerated by abundant moisture found in riparian landscapes and decomposing leaves add nutrients and carbon to the mineral soil. The lowest soil quality is found in fragmented forests in the southern part of the State, where more productive lands have been converted to agriculture.



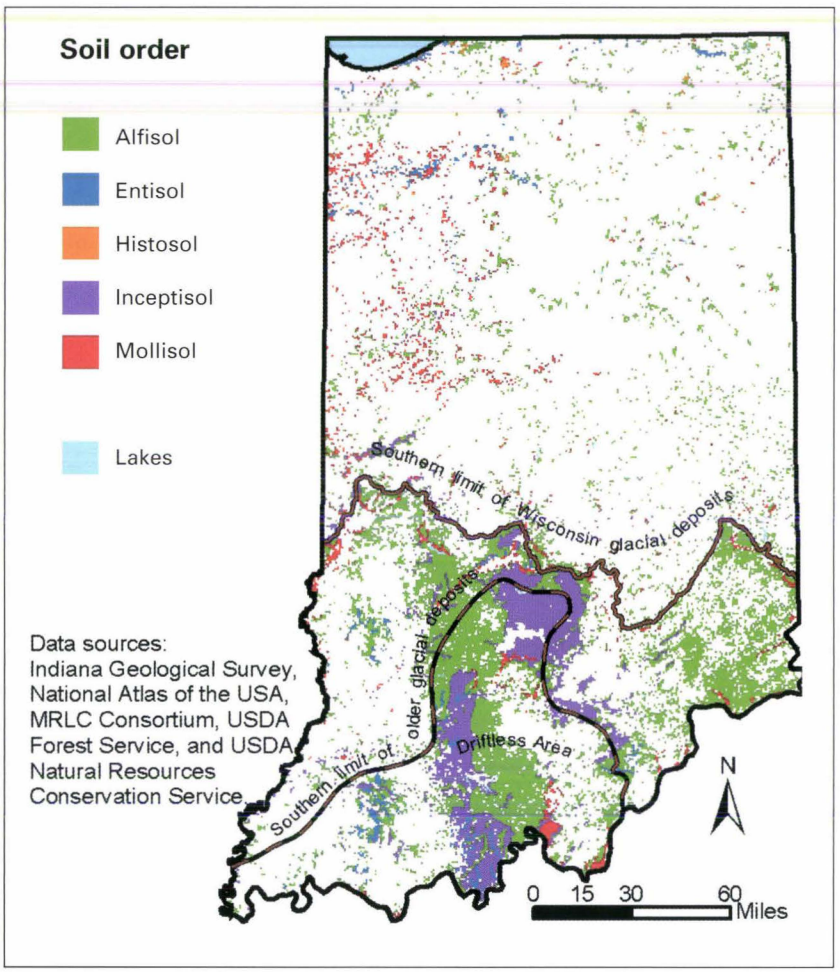


Figure 2.26. Soil orders mapped from the State Soil Geographic (STATSGO) database and updated with the Soil Classification (SC) database.

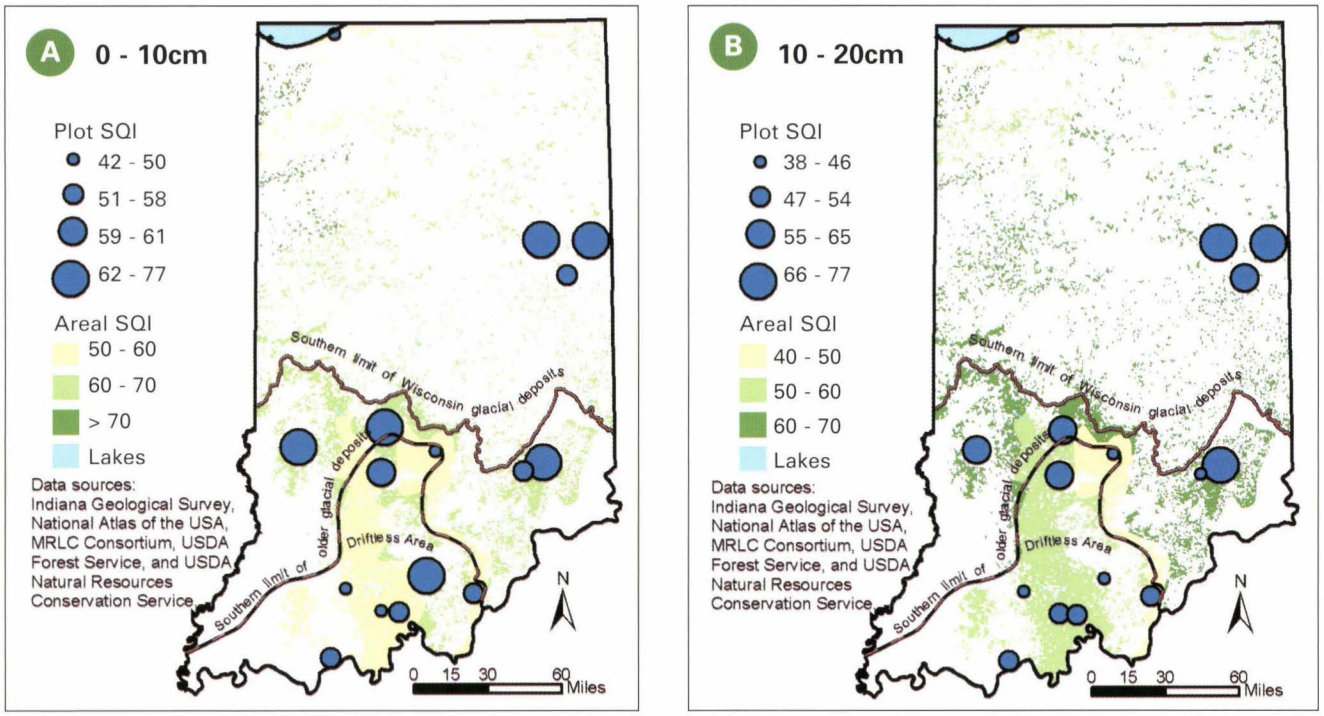


Figure 2.27. Soil quality index for 0–10 and 10–20cm, summarized by Major Land Resource Areas, Indiana, 2001- 2003.

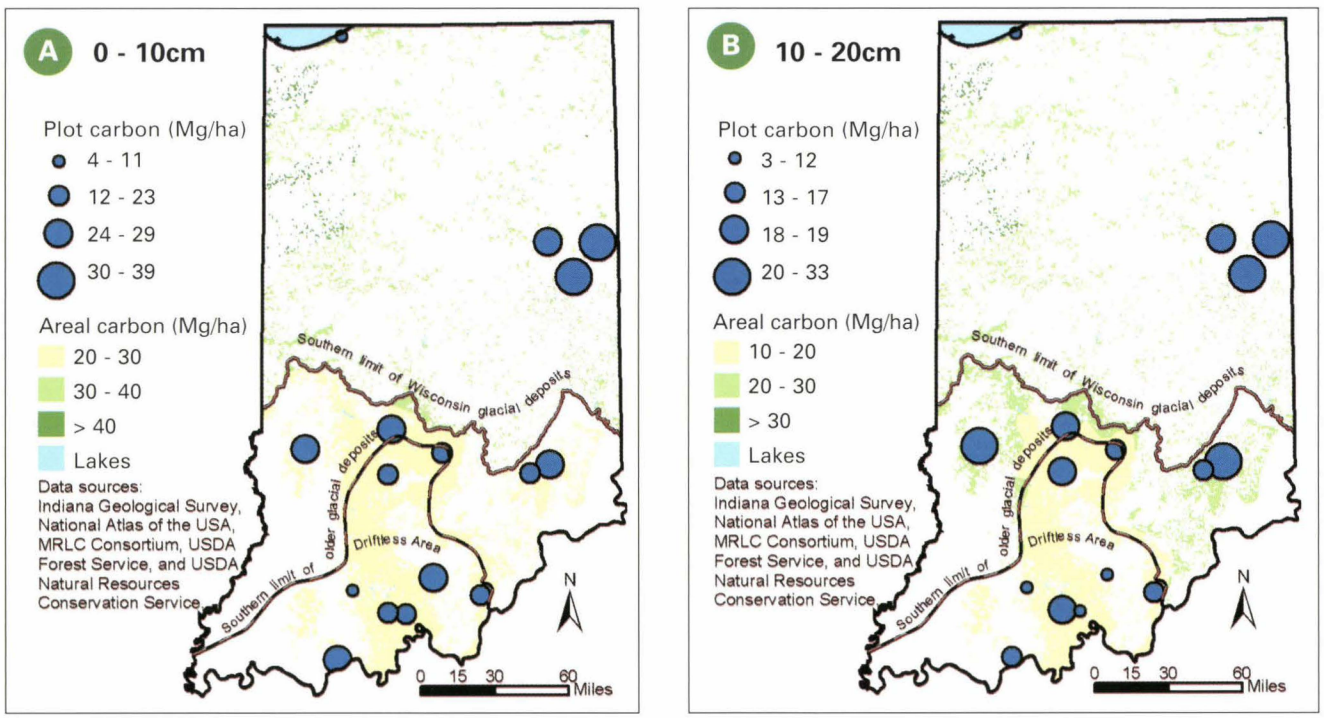


Figure 2.28. Soil carbon storage in the mineral soil (Mg/ha), summarized by Major Land Resource Areas, Indiana, 2001-2003.

Insects and Disease

Background:

During recent decades the health and makeup of Indiana's forests have been greatly altered by insects (e.g., tent caterpillars and gypsy moths) and diseases (e.g., chestnut blight and Dutch elm disease). Monitoring insects and diseases in the context of abiotic agents (e.g., drought) is crucial to predicting and managing Indiana's future forest resources.

What We Found:

Indiana's forests experienced impacts from numerous insects and diseases during 1999-2003 (table 2.1). Of these forest health problems, jumping oak gall (fig 2.29), eastern tent caterpillar (fig. 2.30), looper complex (half-wing geometer and linden looper), forest tent caterpillar, locust leafminer, and flooding caused the most damage within regional areas. Sycamore anthracnose, Dutch elm disease, oak wilt (fig. 2.31), white pine root decline, and ash yellows (Phytoplasma), in combination with drought, also produced subtle to noticeable impacts across the State. Butternut canker continued to affect the limited butternut resource statewide. Pine shoot beetle slowly expanded its range south into new counties each year. Tatters occurred sporadically between 1999 and 2003 to white oak and other oaks primarily in northwest and north-central Indiana, but also to a lesser degree in other areas. Ips, in association with other factors, caused some mortality of pine stands in southern Indiana.

What This Means:

Insects and diseases affected forest land across Indiana during the survey period with varying degrees of severity. Some of these impacts were local or regional and confined to a single year, while others were statewide and ongoing. For the immediate future, Indiana's forests are at serious risk from the introduction and spread of gypsy moth, emerald ash borer, sudden oak death, and invasive plant species (garlic mustard, bush honeysuckle, kudzu, tree-of-heaven, and more). Drought and Dutch elm disease have had statewide impacts, while native insects (e.g., forest tent caterpillar and loopers) have caused mortality and reduced growth in the oak/hickory forests of south-central Indiana. Most other insects and diseases had local impact during the survey period. Although no "hotspots" of widespread mortality are apparent, insect and disease monitoring will remain important as Indiana's forests continue to age and enter late stages of stand development.

Table 2.1. Insects, diseases, and abiotic agents causing impacts to Indiana forests from 1999-2003. (listed in order of importance by amount of damage).

1999	2000	2001	2002	2003
Jumping oak gall	Eastern tent caterpillar	Eastern tent caterpillar	Eastern tent caterpillar	Eastern tent caterpillar
Tatters	White pine root decline	Oak wilt	Jumping oak gall	Looper complex
Drought	Jumping oak gall	Locust leafminer	Sycamore anthracnose	Forest tent caterpillar
Ash yellows	Tatters	White pine weevil	Bagworm	Jumping oak gall
Dutch elm disease	Ash yellows	Gypsy moth	Drought (yellow-poplar)	Sycamore anthracnose
Gypsy moth	Dutch elm disease	Tatters	Sirex woodwasp	Gypsy moth
Oak wilt	Gypsy moth	Drought	Gypsy moth	Winter burn
White pine root decline	Oak wilt	Ash yellows	Oak wilt	Wind desiccation
Butternut canker	Butternut canker	White pine root decline	Pine plantation mortality	Pine plantation mortality
Pine shoot beetle	Pine shoot beetle	Dutch elm disease	Ash yellows	Flooding
		Butternut canker	White pine root decline	Oak wilt
		Pine shoot beetle	Dutch elm disease	Yellow-poplar decline
			Butternut canker	Bitternut hickory mortality
			Pine shoot beetle	Ash yellows
				White pine root decline
				Dutch elm disease
				Butternut canker
				Pine shoot beetle

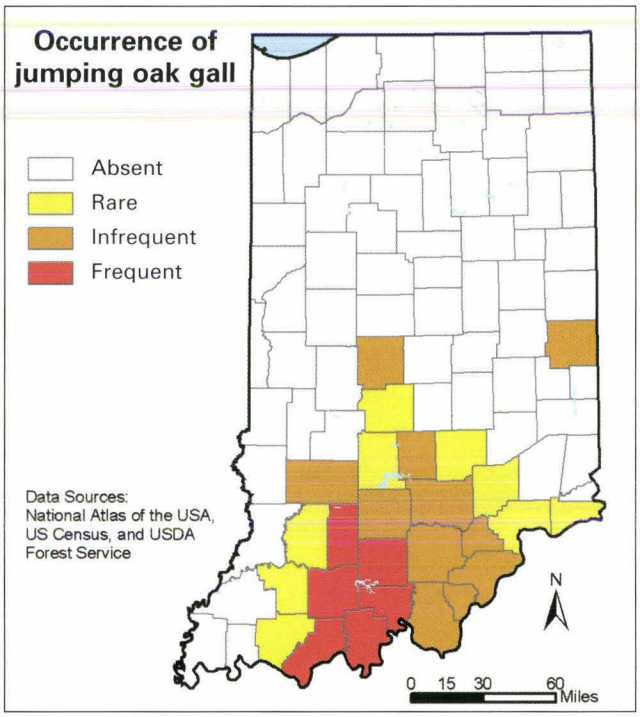


Figure 2.29. Occurrence of Jumping oak gall as detected in Indiana through 1999.

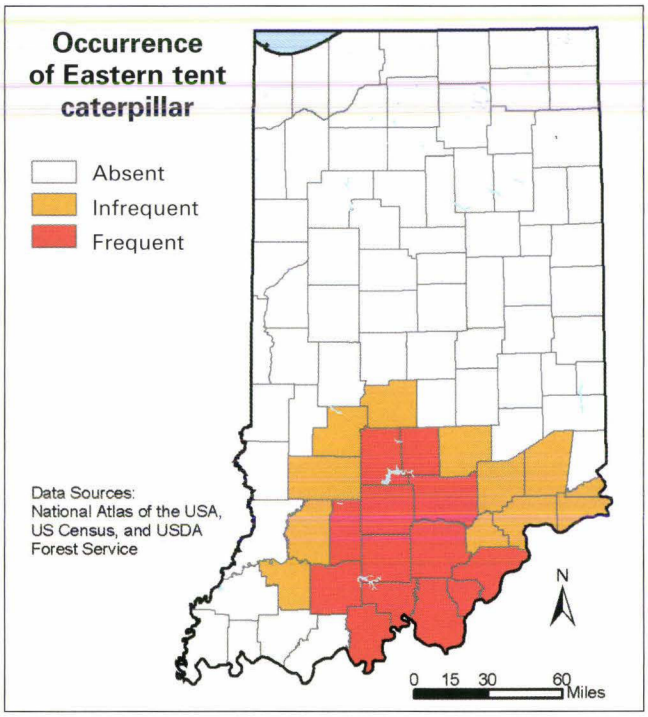


Figure 2.30. Occurrence of Eastern tent caterpillar as detected in Indiana through 2003.

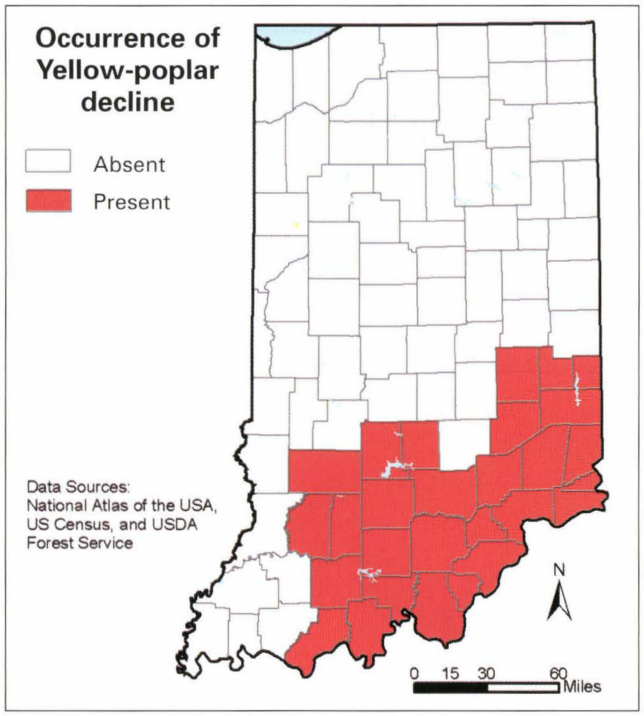


Figure 2.31. Occurrence of yellow-poplar decline as detected in Indiana through 2003.

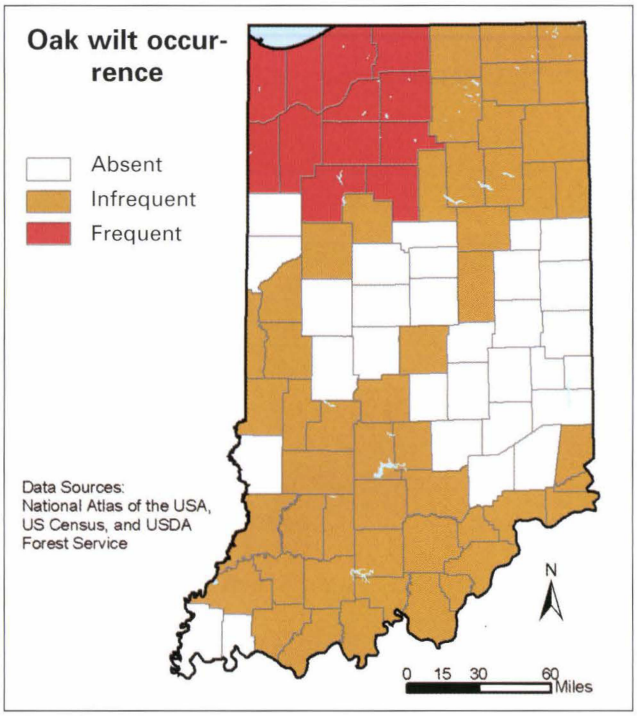


Figure 2.32. Occurrence of oak wilt as detected in Indiana through 2001.

Emerald Ash Borer

Background:

The emerald ash borer is an introduced and invasive bark burrowing insect that can rapidly kill ash trees. Emerald ash borer was first identified in Indiana in April 2004 (LaGrange and Steuben Counties at the time of this report). Although the borer's presence is currently limited in Indiana, forest personnel expect to locate it in additional areas in the future. All forest areas containing ash trees across the State and region are at risk for infestation and loss of the ash component. Therefore, identifying areas containing ash, inventorying ash seedling/sapling amounts, and determining the ratio of ash to non-ash resources are crucial to assessing and mitigating the potential impact of this pest.

What We Found:

Ash trees are fairly well distributed across the Indiana landscape (fig. 2.32). Ash is found in large amounts in the highly fragmented and sparsely forested landscapes of northern Indiana and also in areas of south-central Indiana. Both the northern and south-central survey units have relatively high numbers of ash seedlings and saplings per forested acre. Ash trees have the best regeneration opportunity in more heavily forested south-central Indiana, where each forested acre supports an average of 160 seedlings and 8 saplings (fig. 2.33). Although ash is a component of nearly 1.75 million forested acres in Indiana, it rarely dominates any forest stand (fig. 2.34). In the majority of stands in which ash is present, it represents less than 25 percent of the total live tree basal area.

What This Means:

If the emerald ash borer were to kill all ash trees across Indiana, nearly half of the State's forests would be affected. Forests in the south-central part of the State would be hit hardest, since they possess the largest numbers of ash seedlings and saplings. Mortality would be widespread but probably not devastating because tree species other than ash dominate most of Indiana's forest stands. Following an initial emerald ash borer outbreak, ash would likely survive in forest understories through advance regeneration. Eventually, though, as fewer mature ash trees are available as seed sources, ash could be eliminated or greatly reduced in many forests. Thus, the emerald ash borer could have an impact similar to that of chestnut blight or Dutch elm disease.

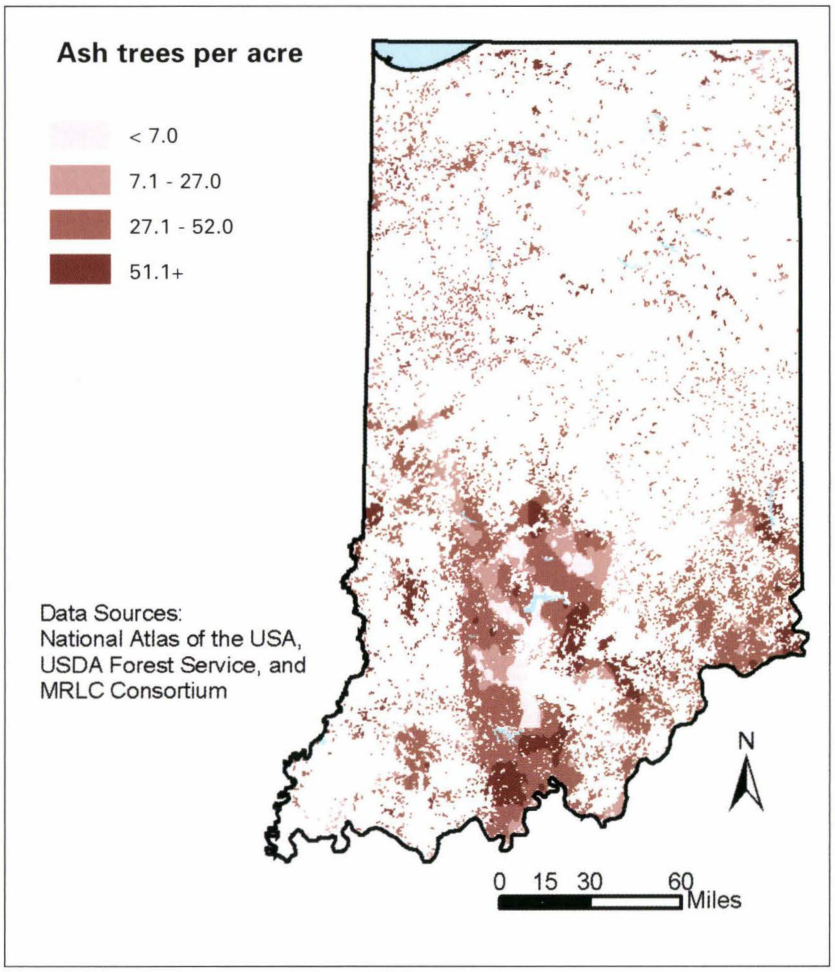


Figure 2.33. Density of ash trees (*Fraxinus spp.*) in Indiana forests (based on inverse distance weighting interpolation), 1999-2003.

Figure 2.34. Mean number of ash seedlings and saplings per acre of forest land by survey unit, Indiana, 1999-2003.

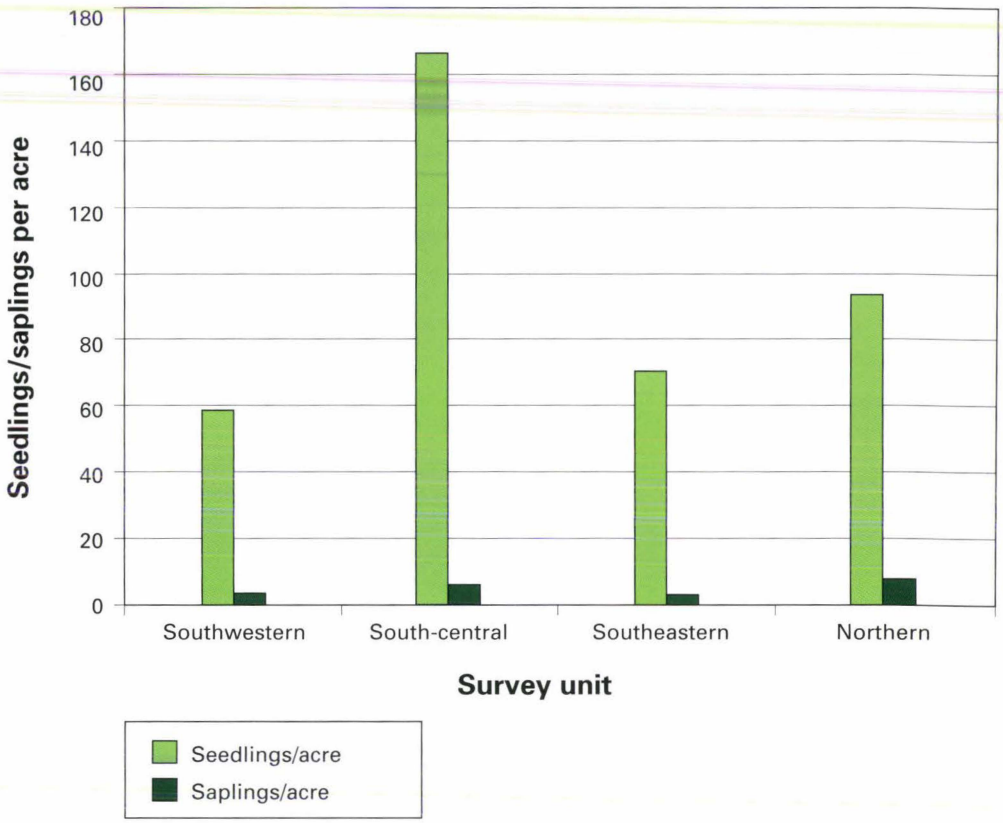
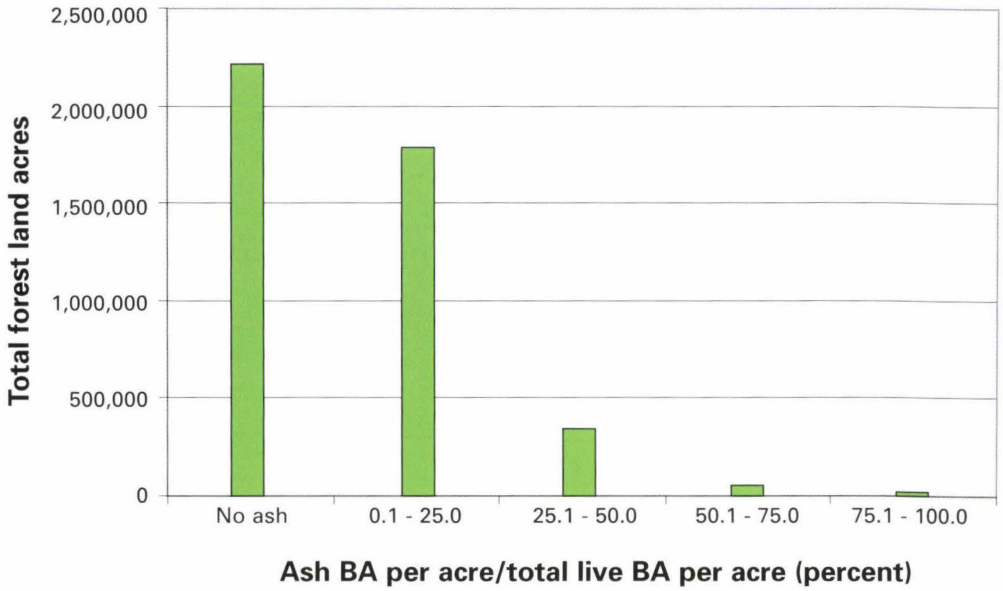
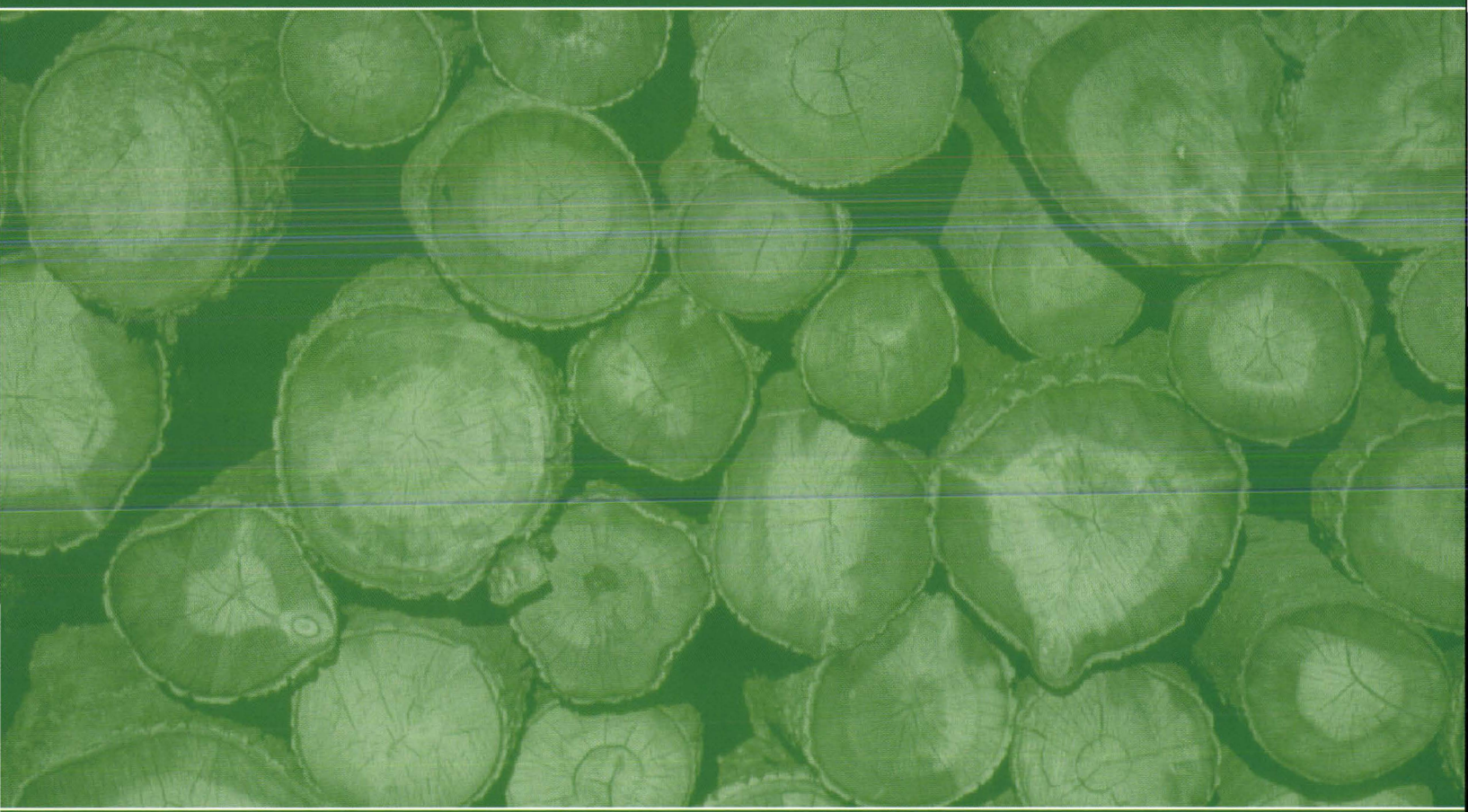


Figure 2.35. Presence of ash in Indiana forests, expressed as percentage of stand basal area (ash BA per acre/total live BA per acre), 1999-2003.





Forest Products

Growing-Stock Volume

Background:

The growing-stock volume on timberland across Indiana constitutes an important portion of Indiana's economic future. In particular, Indiana's forests yield some of the highest quality hardwood products in the world. Assessing the current status and condition of the State's forest volume will help ensure sustainable management and economic prosperity.

What We Found:

The total volume of growing-stock on timberland has been increasing steadily since the 1950 inventory and currently is estimated at 7.5 billion cubic feet (fig. 3.1). The net volume of a variety of hardwood species has increased over the last three inventories (except white oak) (fig. 3.2). Red oaks, followed by yellow-poplar and white oaks, have the largest growing-stock volume across Indiana. Yellow-poplar, in particular, has had the greatest gains in overall net volume since 1986. Most hardwood species have shown an increase in larger diameter volumes since 1986 and a stabilization of smaller diameter volumes (e.g., yellow-poplar) (fig 3.3 a, b, and c). Most Indiana counties have recorded net gains in cubic foot volume, with the largest gains in the heavily forested southern counties (fig. 3.4).

What This Means:

Overall, Indiana's growing-stock volume has been increasing steadily over the past 50 years. Although economically important hardwood species have shown growth in total cubic foot volume and average cubic foot volume per acre, the rate of increase has not been equally apportioned across all hardwoods. Species such as red oak and yellow-poplar have experienced great increases in growing-stock volumes, while white oak and soft maple have shown less robust increases or even slight decreases. The increases in hardwood growing-stock volume can be attributed to development of current hardwood stands, lack of widespread mortality, and an increase in timberland area over the past five decades.

Although the health of Indiana's hardwood growing-stock volumes appear stable, they could be compromised by widespread mortality due to new damage agents, the age-induced mortality of older hardwood stands, and the loss of timberland area to development.

Figure 3.1. Total volume of growing-stock on Indiana's timberland for all five inventories.

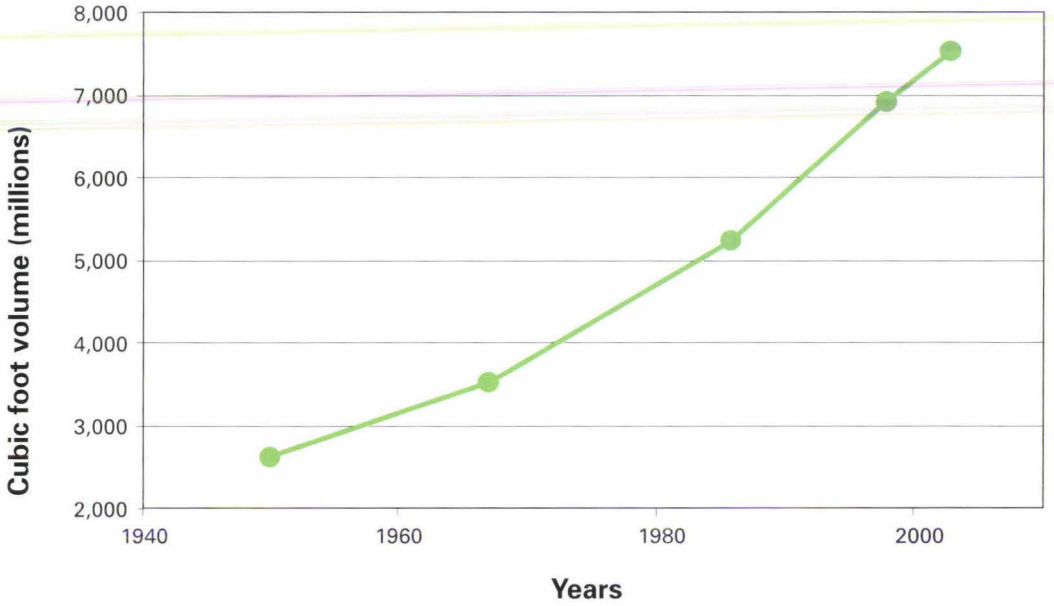


Figure 3.2. Net volume of selected hardwoods in Indiana for the 1986, 1998, and 2003 inventories.

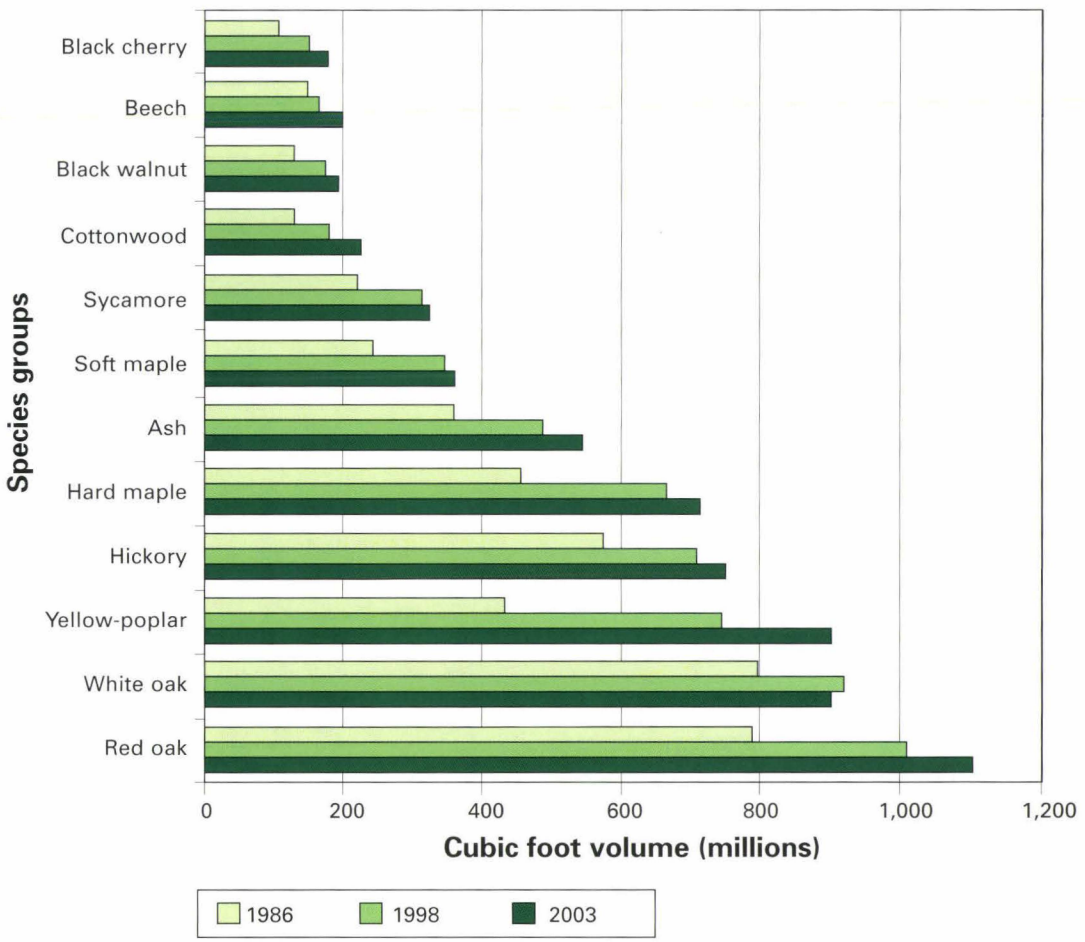
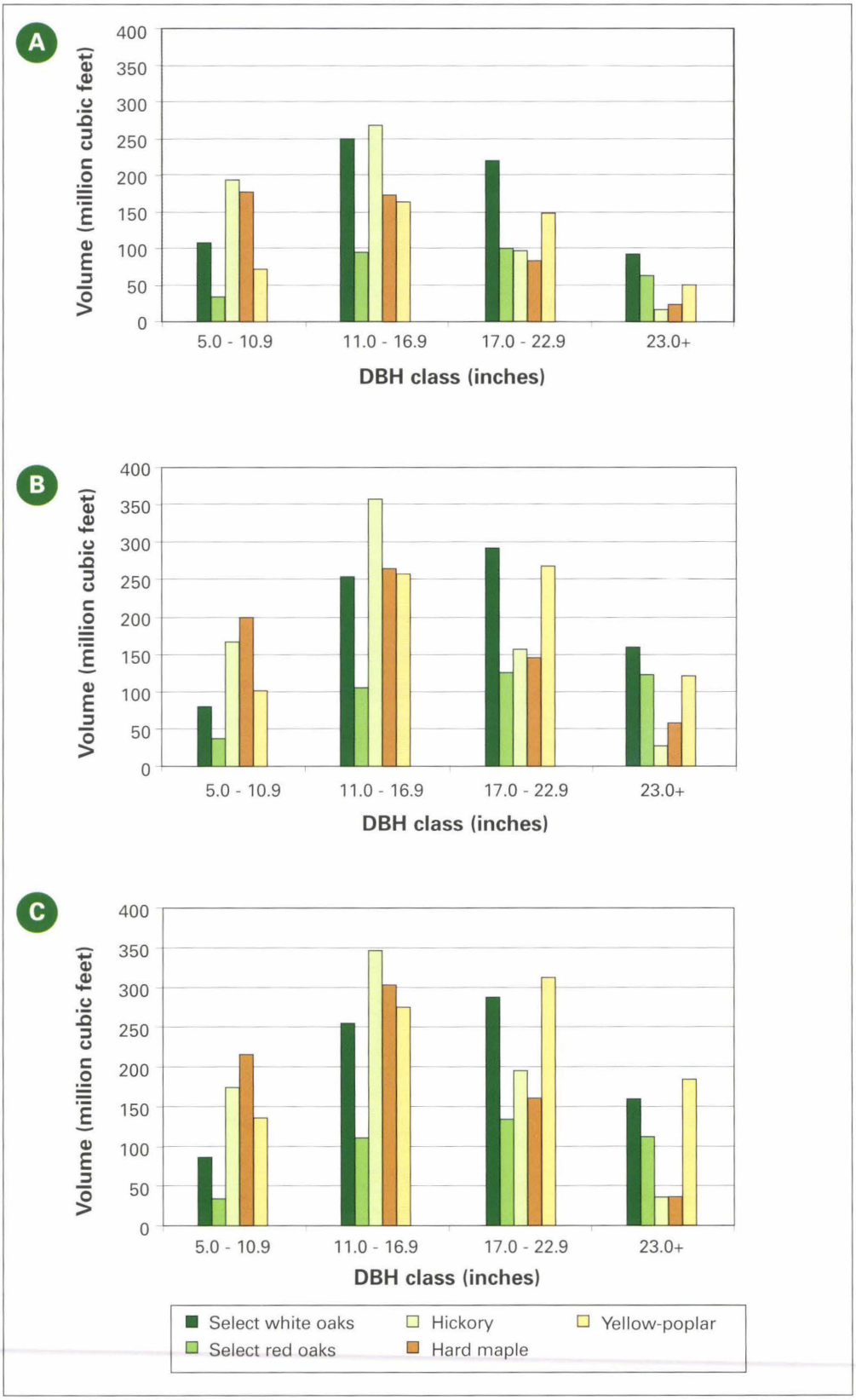


Figure 3.3. Growing-stock volume of selected hardwood species groups by 6-inch d.b.h. classes, Indiana, 1986 (A), 1998 (B), and 2003 (C).



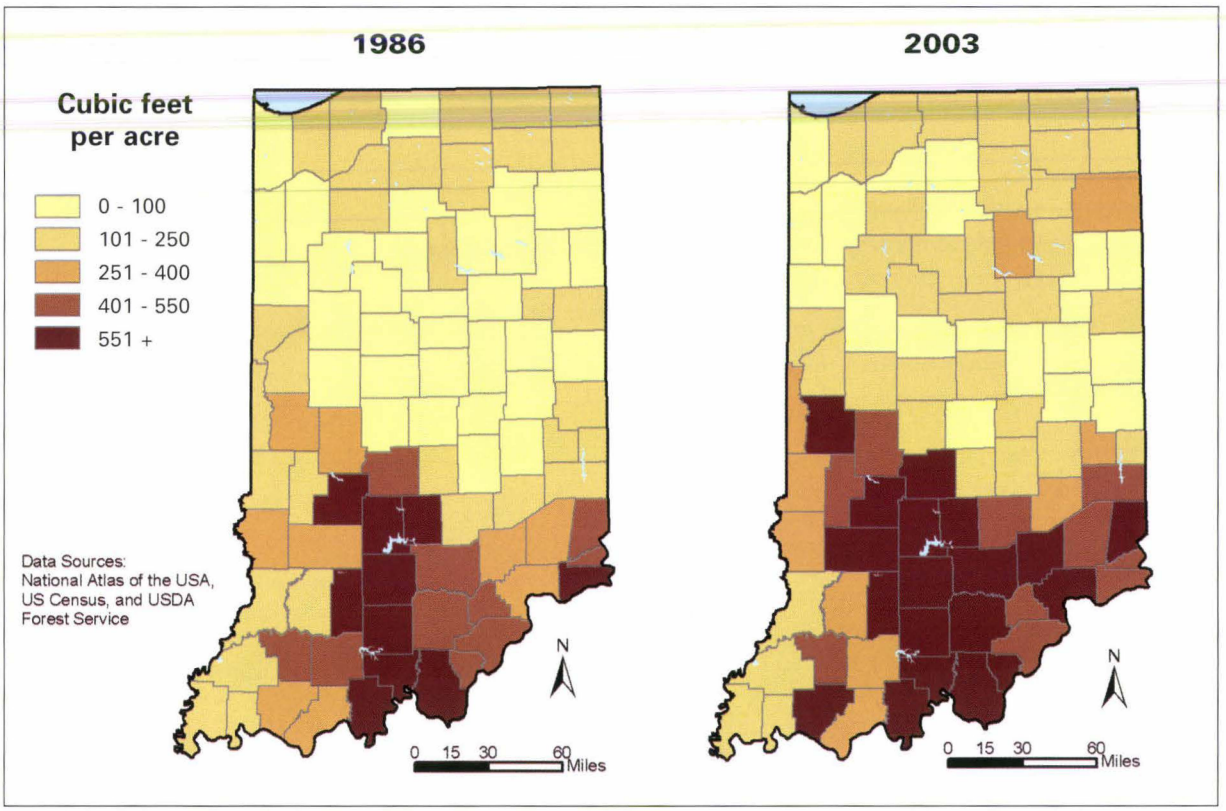


Figure 3.4. Net cubic foot volume per acre (all land area) of growing-stock trees for counties in Indiana, 1986 and 2003.

Sawtimber Volume

Background:

Net sawtimber volume is an important indicator of the economic value of Indiana's forests due to the relatively high market value of that State's fine hardwoods. These hardwood resources not only provide direct economic benefit through timber sales but also support the secondary industries of sawtimber processing and final product manufacture (e.g., furniture and handles).

What We Found:

Since 1967, net sawtimber volume has increased steadily across Indiana and is currently estimated at 28.6 billion board feet (Int. 1/4 inch) (fig. 3.5). Given the current rate of growth, total sawtimber volume on timberland could reach nearly 30 billion board feet by 2008. Most hardwood species of economic interest showed increases in total sawtimber volume since 1998, with yellow-poplar and ash increasing over 15 percent in 5 years. However, select red and white oaks showed little change (fig. 3.6). Since 1967, the average annual net growth of sawtimber with respect to total statewide sawtimber has increased steadily, with average annual mortality increasing only slightly every year (fig. 3.7). Sawtimber removals have stabilized, with only a minor and possibly statistically insignificant increase since 1998.

What This Means:

The sawtimber resources of Indiana's forests have increased since 1967, but this increase has not been uniform across all species groups. Some economically important species, such as select white and red oaks, have had static sawtimber volumes since 1998. Conversely, yellow-poplar has surged in growth and occupancy of timberland areas. Since 1967, average annual sawtimber removals, mortality, and net growth have all stabilized, resulting in a gradual increase in net sawtimber inventory. Although there has been an apparent increase in sawtimber removals since 1998, the standard errors and size of the difference preclude stronger conclusions. Given the increasing pressures of land conversion, invasive pests, and utilization, future mortality, removals, and growth estimates should be closely monitored to ensure sustainable utilization of forest resources.

Figure 3.5. Total sawtimber volume on Indiana's timberland for all five inventories.

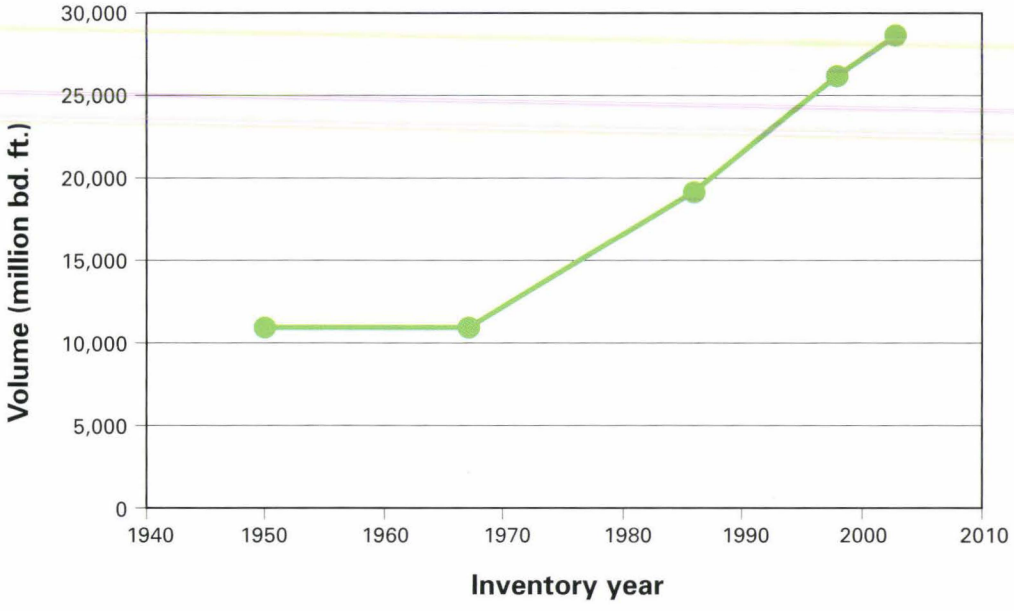


Figure 3.6. Percent change in total sawtimber volume on timberland for selected hardwood species in Indiana between 1998 and 2003.

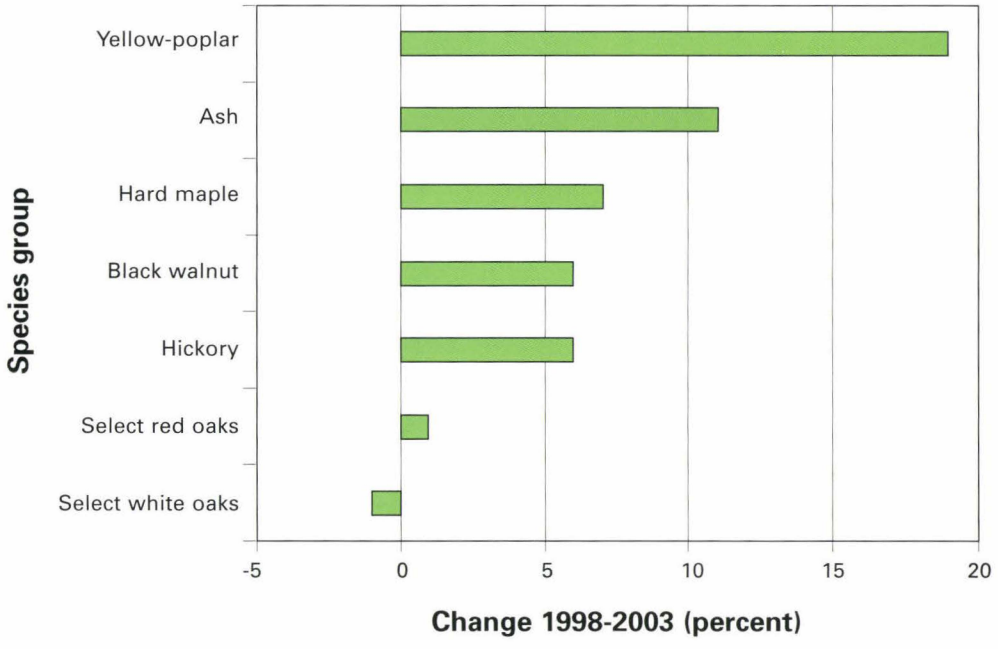
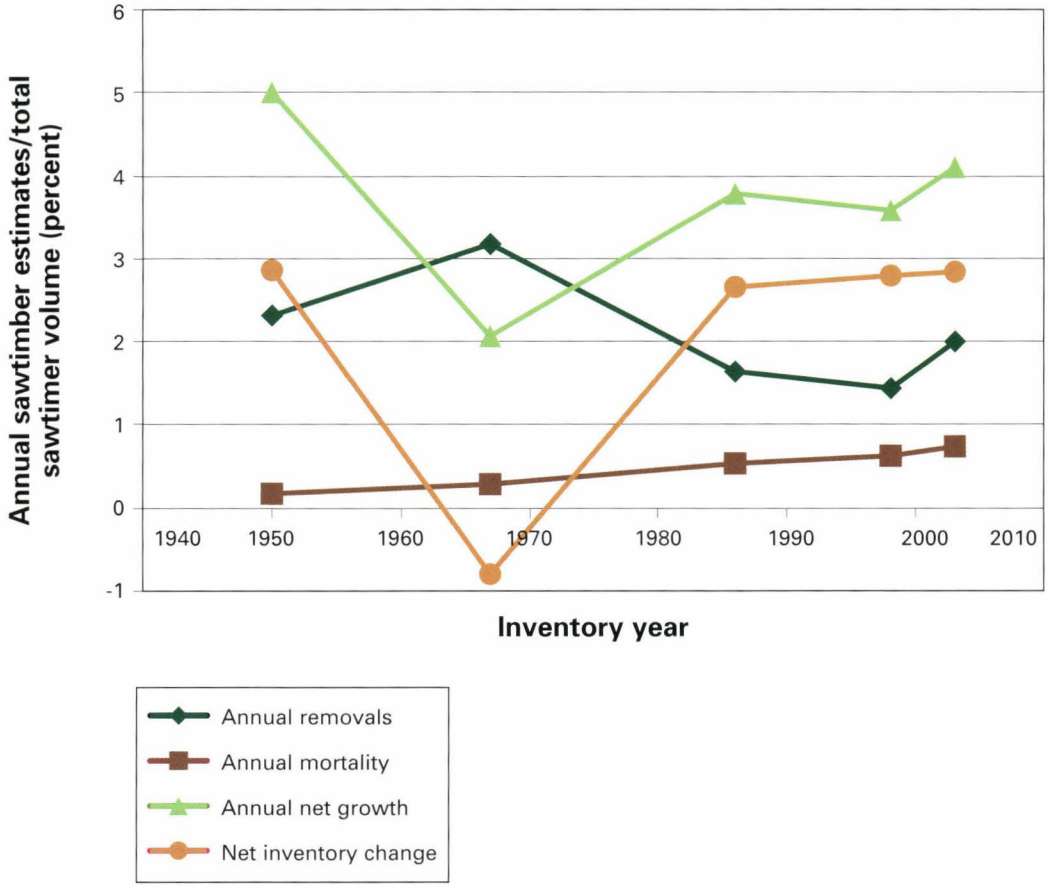


Figure 3.7. Total average annual removals, mortality, net growth, and net inventory change by total sawtimber board foot volume (%) for all five inventories, Indiana, 1950-2003.



Sawtimber Quality

Background:

The economic value of Indiana's sawtimber lies not only in its quantity but also its quality. The generally high grades of hardwood sawtimber support Indiana's reputation of being a leading hardwood producer.

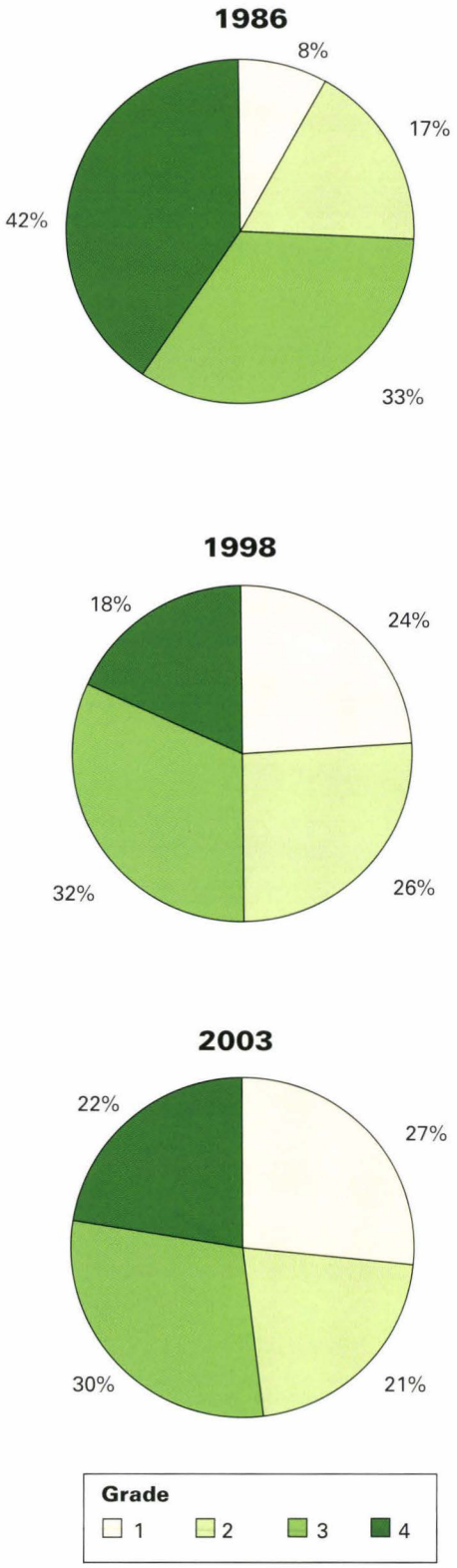
What We Found:

Although grading techniques have changed since previous inventories, Indiana's forests appear to have experienced major increases in sawtimber quality in recent decades. The net volume of grade 1 sawtimber has steadily increased since 1986, both in absolute volume (6.9 billion board feet) and as a percentage of all graded sawtimber (fig. 3.8). In 1986, the volume of grade 1 sawtimber as a percentage of all graded sawtimber was 8 percent, while in 2003 it had increased to 27 percent. Although there have been fluctuations in the proportions of other grades since 1986, the trend has been toward increasing volumes of higher grades. In absolute terms, grade 1 and 2 sawtimber totaled over 12 billion board feet in 2003, compared with only about 8 billion in 1998 and 5 billion in 1986. All important hardwood species have shown increases in sawtimber volumes for grades 1 and 2 since 1986, with hickory recording an almost 100 percent increase in grade 1 sawtimber volume (fig. 3.9).

What This Means:

The quality of Indiana's sawtimber has been increasing for decades, especially in the highest grades, for many economically important tree species. The substantial increases in higher grade sawtimber volumes for commercially important hardwoods are most likely due to individual tree growth increasing the sections of clear boles on ever larger trees, a synergistic interaction. Overall, it appears that Indiana's sawtimber resource has been sustainably managed in recent decades while increasing in quality and subsequent market value.

Figure 3.8. Distribution of tree log grades (volume) for sawtimber in inventory years 1986, 1998, and 2003.



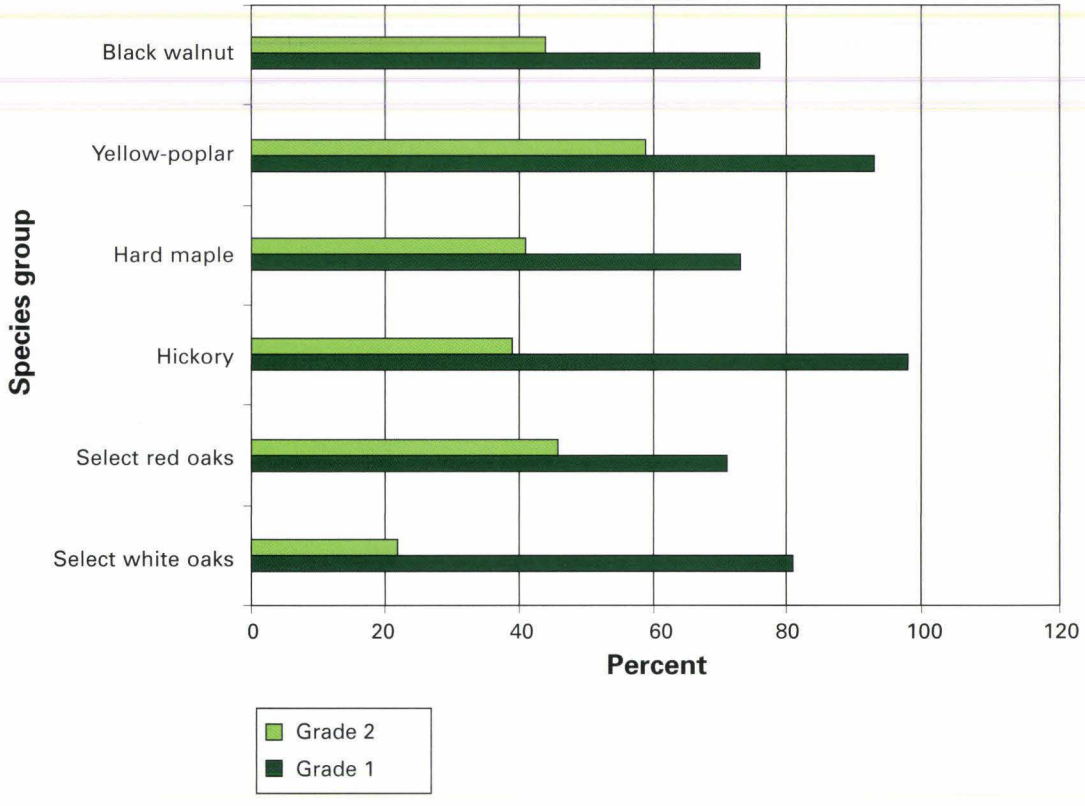


Figure 3.9. Percent increase in sawtimber volume for selected hardwood species in Indiana between 1998 and 2003 for sawtimber grades 1 and 2.

Timber Product Output

Background:

Forest harvest produces a stream of income shared by timber owners, managers, marketers, loggers, truckers, and processors. Almost 9,000 people, with a payroll of $220 million, are employed by primary wood harvesters and processors in Indiana (Bratkovich *et al.* 2004). To better manage the State's forests, it is important to know the species, amounts, and locations of timber being harvested.

What We Found:

We conducted a mill survey to estimate the amount of harvested forest resources and the production of Indiana's mills. Nearly three-fourths of the 79 million cubic feet of industrial roundwood harvested for the primary wood-using industry came from south-central and southwestern Indiana (fig. 3.10). Red oaks accounted for 27 percent of the harvest, followed by yellow-poplar (17 percent), and white oaks (16 percent) (fig. 3.11). All softwoods combined made up less than 1 percent of the volume harvested. Saw logs accounted for 92 percent of the total harvest, with other minor products—primarily veneer logs, pulpwood, handles, and cooperage—making up the rest (fig. 3.12). Ninety-three percent of industrial roundwood production came from growing-stock sources, with limbwood and dead trees accounting for most of the remainder. Ninety-four percent of the industrial roundwood harvested was processed by Indiana mills. The industrial roundwood harvest left 21 million cubic feet (6 percent) of growing-stock material on the ground as logging residue.

What This Means:

The lower than average use of wood fiber in northern Indiana shows the potential for an industrial increase in this area. Limiting factors include the distances harvested logs have to travel for processing, diverse stand species compositions, and small tract sizes. Portable sawmills that can process trees on-site would allow better utilization of forest resources in that part of the State. Saw logs account for more than 90 percent of the industrial roundwood production in Indiana, which means that the upper portions of trees are largely left on the ground as logging residue. An expansion of markets to better utilize smaller diameter hardwood materials is warranted.

Figure 3.10. Industrial roundwood production by region (Forest Survey Unit), Indiana, 2003.

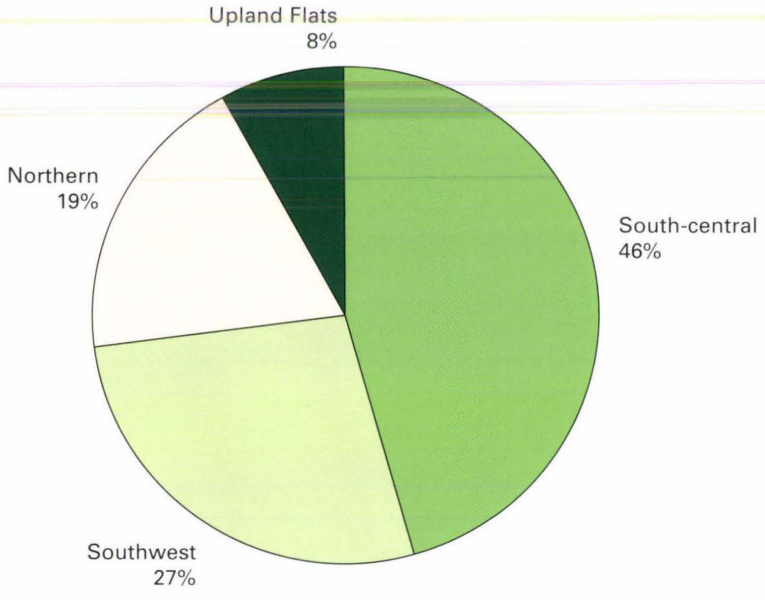


Figure 3.11. Industrial roundwood production by species group, Indiana, 2003.

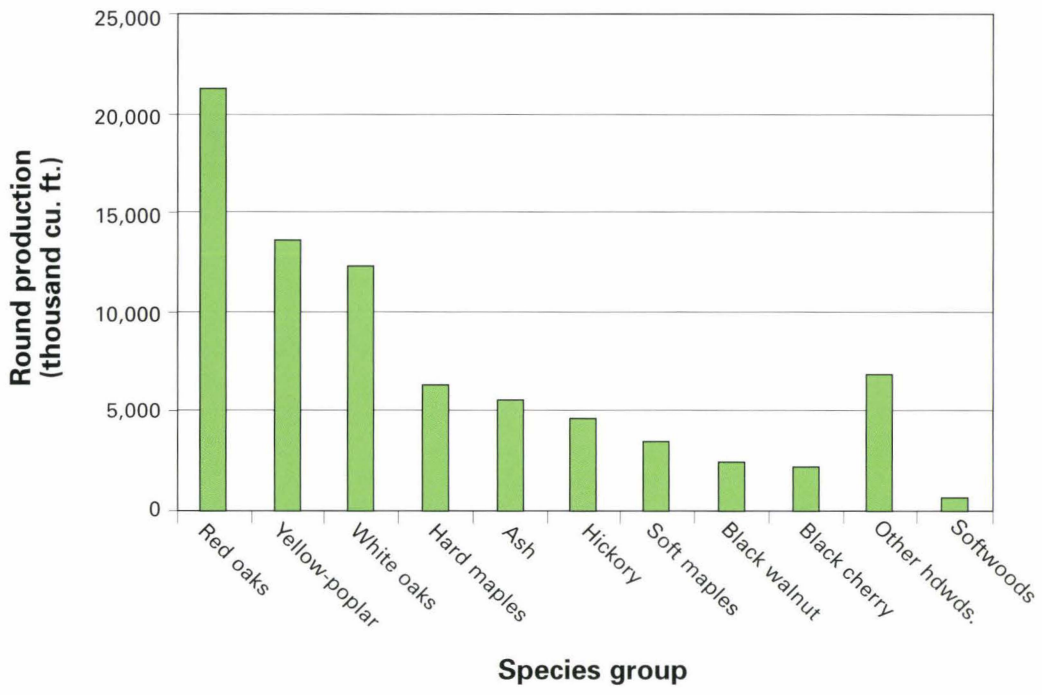
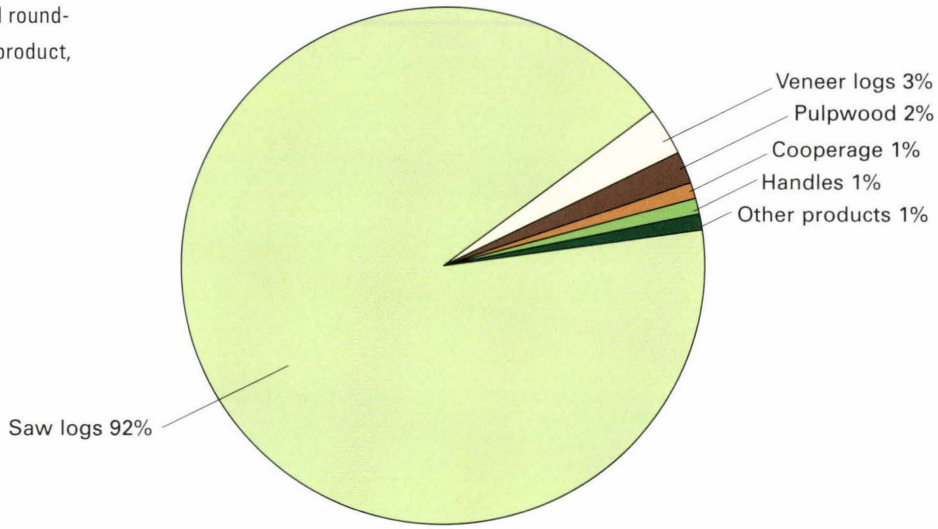


Figure 3.12. Industrial roundwood production by product, Indiana, 2003.



Data Sources and Techniques

Data Sources and Techniques

Forest Inventory

The North Central Research Station's Forest Inventory and Analysis (NCFIA) program began fieldwork for the fifth inventory of Indiana forest resources in 1999. This launched the new annual inventory system in which one-fifth of the field plots (considered one panel) are measured each year. In 2003, NCFIA completed measurement of the fifth and final panel of inventory plots in Indiana. Now that all panels have been measured, each will be remeasured approximately every 5 years. Previous inventories of Indiana's forest resources were completed in 1950, 1967, 1986, and 1998 (Hutchison 1956, Schmidt *et al.* 2000, Smith and Golitz 1988, Spencer 1969, Spencer *et al.* 1990).

Data from new inventories are often compared with those from earlier inventories to determine trends in forest resources. However, for the comparisons to be valid, the procedures used in the two inventories must be similar. As a result of our ongoing efforts to improve the efficiency and reliability of the inventory, several changes in procedures and definitions have been made since the last Indiana inventory in 1998 (Schmidt *et al.* 2000). Although these changes will have little impact on statewide estimates of forest area, timber volume, and tree biomass, they may significantly impact plot classification variables such as forest type and stand-size class (especially county level estimates). For estimating growth, removals, and mortality, the 1998 inventory (Schmidt *et al.* 2000) was processed using estimation/summary routines for the 1999-2003 inventory. Although these changes allow limited comparison of inventory estimates among separate inventories in this report, it is inappropriate to directly compare all portions of the 1999-2003 data with those published for earlier inventories.

The 1999-2003 Indiana forest inventory was done in three phases. During the first phase, we used a computer-assisted classification of satellite imagery to form two initial strata—forest and nonforest. Pixels within 60 meters (2 pixel widths) of a forest/nonforest edge formed two additional strata—forest/nonforest and nonforest/forest. Forest pixels within 60 meters on the forest side of a forest/nonforest boundary were classified into a forest edge stratum. Pixels within 60 meters of the boundary on the nonforest side were classified into a nonforest edge stratum. The estimated population total for a variable is the sum across all strata of the product of each stratum's estimated area and the variable's estimated mean per unit area for the stratum.

The second phase of the forest inventory consisted of the actual field measurements. Current FIA precision standards for annual inventories require a sampling intensity of one plot for approximately every 6,000 acres. The entire area of the United States has been divided into nonoverlapping hexagons, each containing 5,937 acres (McRoberts 1999). The total Federal base sample of plots has been systematically divided into five interpenetrating, nonoverlapping subsamples or panels. Each year the plots in a single panel are measured, and panels are selected on a 5-year, rotating basis (McRoberts 1999). For estimation purposes, the measurement of each panel of plots may be considered an independent systematic sample of all land in a State. Field crews measured vegetation on plots forested at the time of the last inventory and on plots currently classified as forest by trained photointerpreters using aerial photos or digital orthoquads.

NCFIA has two categories of field plot measurements—phase 2 field plots (standard FIA plots) and phase 3 plots (forest health plots) to optimize our ability to collect data when available for measurement. A suite of tree and site attributes is measured on phase 2 plots, while a full suite of forest health variables is measured on phase 3 plots. Both plots types are uniformly distributed both geographically and temporally. The 1999-2003 annual inventory results represent field measurements on 920 phase 2 forested plots and 25 phase 3 plots.

The overall phase 2 plot layout consists of four subplots. The centers of subplots 2, 3, and 4 are located 120 feet from the center of subplot 1. The azimuths to subplots 2, 3, and 4 are 0, 120, and 240 degrees, respectively. Trees with a d.b.h. of 5 inches and larger are measured on a 24-foot-radius ($^1/_{24}$ acre) circular subplot. All trees less than 5 inches in d.b.h. are measured on a 6.8-foot-radius ($^1/_{300}$ acre) circular microplot located 12 feet east of the center of each of the four subplots. Forest conditions that occur on any of the four subplots are recorded. Factors that differentiate forest conditions are changes in forest type, stand-size class, land use, ownership, and density. For details regarding the sample protocols for phase 2 variables and all phase 3 indicators, please refer to http://fia.fs.fed.us/library/fact-sheets/.

Timber Products Inventory

This study was a cooperative effort of the Division of Forestry of the Indiana Department of Natural Resources (INDNR) and the North Central Research Station (NCRS). Using a questionnaire designed to determine the size and composition of Indiana's forest products industry, its use of roundwood (round sections cut from trees), and its generation and disposition of wood residues, Indiana Division of Forestry personnel visited all "known" primary wood-using mills within the State. Completed questionnaires were sent to NCRS for editing and processing. As part of data editing and processing, all industrial roundwood volumes reported on the questionnaires were converted to standard units of measure using regional conversion factors. Timber removals by source of material and harvest residues generated during logging were estimated from standard product volumes using factors developed from logging utilization studies previously conducted by NCRS.

National Woodland Landowner Survey

This survey of private forest owners is conducted annually by the USDA Forest Service. The purpose of this survey is to increase the understanding of private woodland owners—the critical link between forests and society. Every year, questionnaires are mailed to individuals and private groups who own woodlands where FIA has established forest inventory plots. Twenty percent of these ownerships (about 50,000) are contacted each year, with more detailed questionnaires sent out in years that end in 2 or 7 to coincide with national census, inventory, and assessment programs.

NLCD Imagery

Derived from Landsat Thematic Mapper satellite data (30-meter pixel), the National Land Cover Data (NLCD) is a land cover classification scheme (21 classes) applied across the United States by the U.S. Geological Survey (USGS) and the U.S. Environmental Protection Agency (EPA). The NLCD was developed from data acquired by the Multi-Resolution Land Characterization (MRLC) Consortium, a partnership of federal agencies that produce or use land cover data. Partners include the USGS, EPA, USDA Forest Service, and the National Oceanic and Atmospheric Administration.

Insects and Diseases

The Indiana DNR receives cooperative forest protection funding from the USDA Forest Service's Forest Health Monitoring program (FHM) to survey and monitor all insects and pathogens in the State on an ongoing basis. Additional FHM funding was provided in recent years to augment State-conducted ground surveys for defoliators and mortality from all damage agents. Some projects (e.g., emerald ash borer, sudden oak death, gypsy moth) also received supplemental support. On Indiana's Federal lands (e.g., Hoosier National Forest and Big Oaks National Wildlife Refuges), aerial surveys to detect defoliation and mortality are done through the USDA Forest Service's Forest Health Protection program (FHP). The Indiana DNR is responsible for similar surveys on State and private lands.

Mapping Procedures

Maps in this report were generated by either categorical coloring of Indiana counties (based on 1990 U.S. Census) according to forest attributes (such as forest land area), or interpolating forest attributes using inverse distance weighting techniques and masking out nonforest land using NLCD imagery. Because the forest inventory is based on plot data collected at distinct points, inferences must be drawn about the entirety of Indiana's forests. Interpolation between plot locations allows creation of forest attribute maps that display continuous spatial estimates. Inverse Distance Weighting (IDW), which assumes that things close to one another are more alike than those farther apart, is the interpolation method employed in this report. To predict a value for any unmeasured location, IDW uses the measured values surrounding the unmeasured location. This assumes that each measured point has a local influence that diminishes with distance, thus the term "inverse distance weighting." For more information, see Johnston *et al.* (2001).

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The first completed annual inventory of Indiana's forests reports more than 4.5 million acres of forest land with a diverse array of forest types, substantial growth of economically valuable tree species, and future forest health concerns such as invasive species, forest fragmentation, and oak forest decline.

KEY WORDS: forest area, forest health, completed annual inventory

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